Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

REPORT

for

1949

To be obtained from the Secretary
Price 5/- (Foreign Postage Extra)

Telephone and Telegrams
Harpenden 3621-23

Station
Harpenden L.M.R.

ST. ALBANS
GIBBS & BAMFORTH LTD.
1950

1 SEP 1950

Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

REPORT

for

1949

To be obtained from the Secretary
Price 5/- (Foreign Postage Extra)

Telephone and Telegrams
Harpenden 3621-23

Station
Harpenden L.M.R.

ST. ALBANS
GIBBS & BAMFORTH LTD.
1950

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914-1915.

CONTENTS

	Page
The Lawes Agricultural Trust	5
The Incorporated Society for extending the Rothamsted Experiments	5
Staff of the Rothamsted Experimental Station	6
Staff of the Soil Survey of England and Wales	12
Staff of the Woburn Experimental Station	13
Staff of the Imperial College of Science and Technology —Research Institute of Plant Physiology	13
The Commonwealth Bureau of Soil Science	14
Preface	15
Introduction	17
Departmental Reports	
PHYSICS	25
CHEMISTRY	30
PEDOLOGY	37
SOIL MICROBIOLOGY	41
BOTANY	47
STATISTICS	53
PLANT PATHOLOGY	59
BIOCHEMISTRY	65
NEMATOLOGY	68
ENTOMOLOGY	76
BEES	80
INSECTICIDES AND FUNGICIDES	86
FIELD EXPERIMENTS	93
THE FARMS—ROTHAMSTED	105
WOBURN	110
WOBURN EXPERIMENTAL STATION	114
Soil Survey of England and Wales	119
Special Reviews	
NUTRITIONAL PROBLEMS IN FOREST NURSERIES	122
THE RELATION BETWEEN SOIL CULTIVATION AND CROP YIELDS	130
Departmental Publications	148
Publications of the Station	174
Map of the Rothamsted Farm	179

The Lawes Agricultural Trust

Trustees

THE RIGHT HONOURABLE LORD CLINTON, P.C., G.C.V.O., D.L.

THE RIGHT HONOURABLE THE EARL OF RADNOR, K.C.V.O.

SIR EDWARD J. SALISBURY, C.B.E., D.Sc., F.L.S., SEC.R.S.

Lawes Agricultural Trust Committee

THE RIGHT HONOURABLE THE EARL OF RADNOR, K.C.V.O. (Chairman)

PROFESSOR F. T. BROOKS, C.B.E., M.A., LL.D., F.R.S. (Treasurer)

SIR EDWARD B. BAILEY, M.C., LL.D., D.Sc., D.S., M.A., F.R.S.

PROFESSOR A. C. CHIBNALL, Sc.D., F.R.S.

SIR NORMAN HAWORTH, D.Sc., LL.D., F.R.S.

Dr. J. RAMSBOTTOM, O.B.E., M.A.

SIR EDWARD J. SALISBURY, C.B.E., D.Sc., F.L.S., SEC.R.S.

SIR ARCHIBALD WEIGALL, Bt., K.C.M.G.

SIR WILLIAM G. OGG, M.A. (Secretary)

The Incorporated Society for Extending the Rothamsted Experiments in Agricultural Science

The purpose of the Society is to collect funds for continuing and extending the work of the Rothamsted Station.

Council

HIS GRACE THE DUKE OF DEVONSHIRE (Chairman)

THE RIGHT HONOURABLE LORD CLINTON, P.C., G.C.V.O., D.L.

THE RIGHT HONOURABLE LORD BURGHLEY

THE RIGHT HONOURABLE THE EARL OF PORTSMOUTH

together with members of the Lawes Agricultural Trust Committee as above.

Rothamsted Experimental Station

LIST OF STAFF

DECEMBER, 1949

Director: SIR WILLIAM G. OGG, M.A.

Secretary: J. B. BENNETT, A.C.A.

Physics Department—

Head of Department	...	R. K. SCHOFIELD, M.A., PH.D., F.INST.P.
Scientific Staff ...	...	G. H. CASHEN, M.SC. W. W. EMERSON, B.A. W. C. A. HUTCHINSON, B.SC., PH.D. I. LONG H. L. PENMAN, B.SC., PH.D., F.INST.P. A. W. TAYLOR, B.SC., M.SC.
Temporary Worker	...	H. C. ASLYNG, M.SC.
Assistant Staff ...	...	W. C. GAME, JOSEPHINE NOOND, D. PEARCE, MRS. B. SOMMERTON, JESSIE A. J. WALKER

Chemistry Department—

Head of Department	...	E. M. CROWTHER, D.SC., F.R.I.C.
Scientific Staff ...	...	BLANCHE BENZIAN, B.SC., F.G.S. J. M. BREMNER, B.SC., PH.D. ELIZABETH H. COOKE, B.SC. G. W. COOKE, B.SC., PH.D., A.R.I.C. SIGNE G. HEINTZE, M.PHIL. B. RICKSON, B.SC., A.R.I.C. EDNA ROCKLIFFE ELIZABETH ROSCOE, B.SC. H. A. SMITH R. G. WARREN, B.SC. F. V. WIDDOWSON, B.SC.
Temporary Worker	...	R. S. BECKWITH, B.SC.
Assistant Staff ...	...	E. BIRD, M. A. CLARKE, F. COWLAND, NELLIE CRESSEY, S. C. R. FREEMAN, CYNTHIA HENDEN, G. INGRAM, MARJORIE MANLEY, BETTY POND, G. REES, M. ROBERTS, F. J. SEABROOK, E. JUDY SMITH, J. R. WILKINSON

Soil Microbiology Department—

Head of Department ...	H. G. THORNTON, D.Sc., F.R.S.
Scientific Staff	LETTICE M. CRUMP, M.Sc., F.Z.S. P. C. T. JONES, B.Sc., A.R.C.S. JANINA KLECZKOWSKA, B.Sc., PH.D. JANE MEIKLEJOHN, PH.D. JANET E. MOLLISON, B.Sc., PH.D. P. S. NUTMAN, B.Sc., PH.D., A.R.C.S. B. N. SINGH, M.Sc., PH.D., D.Sc. F. A. SKINNER, B.A.
Temporary Worker ...	I. D. BLAIR, M.Agr.Sc., M.Sc., PH.D.
Assistant Staff	JOAN CRAWLEY, MABEL DUNKLEY, MARGARET HUGHES, ELISABETH MCCALL, JANET ROFFE

Pedology Department—

Head of Department ...	A. MUIR, B.Sc., PH.D.
Scientific Staff	C. BLOOMFIELD, B.Sc. G. BROWN, B.Sc. R. GREENE-KELLY, B.Sc. D. M. C. MACEWAN, M.A., B.Sc., PH.D. I. STEPHEN, B.Sc. O. TALIB-UDDEEN, B.Sc., PH.D.
Assistant Staff	BETTY EWENS, DENISE A. GRAY, D. N. GREET, AUDREY MORGAN, A. W. S. MOULD

Botany Department—

Head of Department ...	D. J. WATSON, M.A., PH.D.
Scientific Staff	E. C. HUMPHRIES, B.Sc., PH.D. P. C. OWEN, B.Sc. GILLIAN N. THORNE, B. A. JOAN M. THURSTON, B.Sc. KATHARINE WARINGTON, D.Sc.
Temporary Worker ...	J. H. WILSON, B.AGR.SC.
Special part-time worker	WINIFRED E. BRENCHLEY, O.B.E., D.Sc., F.L.S.
Assistant Staff	MARJORIE ANDREWS, BARBARA BISHOP, S. A. W. FRENCH, BRENDA MESSER, HEATHER PELLANT, ANNETTE REVITT

Statistics Department—

Head of Department	...	F. YATES, Sc.D., F.R.S.
Scientific Staff	... ...	P. R. D. AVIS, B.Sc. D. A. BOYD, PH.D. B. M. CHURCH, B.Sc. J. H. A. DUNWOODY, B.A. G. V. DYKE, M.A. P. M. GRUNDY, PH.D. M. J. R. HEALY, B.A. G. M. JOLLY, B.Sc. ROWENA LORD, B.Sc. H. D. PATTERSON, M.Sc. EMILY P. POULTON, B.A.
Temporary Workers	...	J. A. NELDER, B.A. J. QUARTEY D. H. REES, B.Sc., A.R.C.S. R. WICKENS, B.A. HILARY J. WILTON
Assistant Staff	... ...	DOROTHY BROWNING, Mrs. D. COURT (part-time), Mrs. W. DAWSON, MARJORIE FULFORD, GWENDOLINE HALSEY, CONSTANCE HUNT, RUTH HUNT (Secretary), Mrs. G. LUCAS, SUSAN OLIPHANT, AUDREY PINCOMBE, Mrs. V. ROBERTS (part-time), FREDA A. SMITH, SYLVIA SMITH, DOREEN TUCKER, W. J. WALTERS, JOAN WILKINSON

Plant Pathology Department—

Head of Department	...	F. C. BAWDEN, M.A., F.R.S.
Scientific Staff	... ...	J. W. BLENCOWE, B.Sc. L. BROADBENT, B.Sc., PH.D. MARGARET M. BROWNE C. E. CORNFORD, PH.D. LINA CUNOW L. F. GATES, B.A. MARY D. GLYNNE, D.Sc. P. H. GREGORY, PH.D., D.Sc. BRENDA M. G. HAMLYN, B.Sc. R. HULL, PH.D. B. KASSANIS, B.Sc., PH.D. A. KLECZKOWSKI, M.D., PH.D. I. MACFARLANE, B.Sc. H. L. NIXON, M.A. FLORENCE M. ROBERTS, M.Sc., PH.D. G. A. SALT, M.A. T. W. TINSLEY, B.Sc. MARION A. WATSON, M.A., PH.D.
Temporary Worker	...	R. H. E. BRADLEY, B.Sc.

Assistant Staff	... ...	Jean Bloomfield, A. W. Halsey, D. P. Hucklesby, Jean Matthews, W. N. Moore, Mrs. M. Roberts (part-time), Joan Sampson, O. J. Stedman, Coral Wick

Biochemistry Department—

Head of Department	...	N. W. Pirie, M.A., F.R.S.
Scientific Staff	... ...	E. Margaret Holden, B.Sc. R. H. Kenten, B.Sc. P. J. G. Mann, B.Sc., Ph.D. D. S. Miller, B.Sc. G. Parker, B.Sc., Ph.D. W. R. Smithies, B.Sc., Ph.D. M. V. Tracey, M.A.
Assistant Staff	... ...	M. L. Barnes, B. Brady, R. N. Danks, Ann P. Field, Pauline Platts, Margery Soundy

Nematology Department—

Head of Department	...	T. Goodey, O.B.E., D.Sc., F.R.S.
Scientific Staff	... ...	D. W. Fenwick, M.Sc. Mary T. Franklin, B.Sc., Ph.D. J. B. Goodey, B.Sc. B. G. Peters, M.Sc., Ph.D.
Assistant Staff	... ...	S. T. Eames, Sylvia Else, Elizabeth Reid, Monica Waller

Entomology Department—

Head of Department	...	C. B. Williams, M.A., Sc.D.
Scientific Staff	... ...	H. F. Barnes, M.A., Ph.D. R. J. French, B.Sc. C. G. Johnson, D.Sc., Ph.D. D. B. Long, B.A. G. Owen Evans, M.Sc., Ph.D. F. Raw, B.Sc., Ph.D. Barbara M. Stokes, B.Sc. L. R. Taylor
Assistant Staff	... ...	B. Buckingham, Mrs. E. Koller, Judith Horn, Mrs. J. Maslin, Biddy Nash, M. O'Connor

Bee Department—

Head of Department	...	C. G. Butler, M.A., Ph.D.
Scientific Staff	... ...	Elizabeth Carlisle C. R. Ribbands, M.A. J. Simpson, B.A. Agnes W. Speirs, C.D.H.
Temporary Workers	...	M. Hassenein, B.Sc. Gwyneth R. Wykes, M.Sc.
Assistant Staff	... ...	J. Clifford, N. Ellement, P. Howard, Marion Nunn, Joan Saunders, M. Tolputt, Joyce White, Joan Wilson

Insecticides and Fungicides Department

Head of Department ...	C. POTTER, D.Sc., PH.D., D.I.C.
Scientific Staff	P. M. BURT, B.A. M. ELLIOTT, B.Sc. EILEEN M. GILLHAM, B.Sc. K. A. LORD, B.A., PH.D., A.R.I.C. A. H. MCINTOSH, B.Sc., PH.D., A.R.I.C. P. H. NEEDHAM, B.Sc. PAULINE M. SMITH, B.Sc. M. J. WAY, B.A.
Temporary Worker ...	T. D. MUKHERJEA, B.Sc., Assoc. I.A.R.I.
Special part-time worker	F. TATTERSFIELD, O.B.E., D.Sc., F.R.I.C.,
Assistant Staff	A. J. ARNOLD, PATRICIA BALL, VANDA BERRY, R. HINTON, JEAN HOLLAND, BARBARA HOPKINS, Mrs. L. TAYLOR, K. J. TOWNSEND

Field Experiments Section—

Head of Section	H. V. GARNER, M.A., B.Sc.
Staff	M. J. ALLEN MYRTLE HUGHES (Clerical Assistant) KATHLEEN J. SKIDMORE, N.D.D. J. W. WEIL, M.A. B. WESTON (Field Superintendent)

Farm Staff—

Farm Manager	J. R. MOFFATT, B.Sc., N.D.A., A.I.B.A.E.
Assistants to Farm Manager	G. COLE, C. R. L. SCOWEN
Secretary	PAULINE COPE J. MARGARET DANCY (part-time assistant)
Experimental Assistant ...	P. G. HENDEN
Foreman	H. P. CURRANT
Farm Workers	T. E. ABLEWHITE, J. BIRD, P. BIRD, W. A. H. BURTON, W. CAIN, H. S. CHAPMAN, P. W. CURRANT, B. DAY, K. V. EWING, G. KUNATH, A. MILLS, DEIRDRE A. RAWES, K. R. SEARS, E. STEVENS, F. STOKES, J. UNDERHILL, H. A. WALFORD, F. WEST, R. T. WOOLSTON, L. WRIGHT

Administrative and Clerical Staff—

Assistant Secretary ...	CONSTANCE K. CATTON
Director's Personal Assistant	Mrs. H. ASHBY SMITH
Senior Assistants ...	Mrs. S. COLEMAN MILDRED E. ASHFORD PHYLLIS L. TIMBERS

Junior Clerks	Mary Gooding
	Stella Smith
	Beryl Thorne
Part-time Assistant ...	Barbara J. Bushell

Library—

Librarian	Mrs. M. J. Way, M.A.
Library Assistants ...	K. Toni Sumner
	Sheila Webb

Photography—

Photographer	V. Stansfield, F.R.P.S.
Part-time Draughtswoman	Barbara J. Bushell

Canteen—

Housekeeper	Marjorie Bloomfield
Assistants	Mrs. E. Hawes
	Mrs. M. Holland
	Fanny Jenkinson

Maintenance Staff—

Storekeepers	A. Ogglesby
	A. H. Bowden
Engineer, Joiner, ...	A. E. Hall
Plumber etc.	A. W. Primmett
	B. S. Edwards
	L. R. Smith
Caretakers, Cleaners,	L. Allen
Gardeners etc.	B. G. Burgess
	W. S. Fisher
	J. H. Hall
	F. Hamilton
	Mrs. F. Hamilton
	F. K. Hawkins
	G. E. Hooper
	T. Jackson
	D. McNeal
	E. Needham
	R. C. Parrott
	Mrs. R. C. Parrott
	W. K. Smith
	Mrs. Smith
	F. J. Stock
	H. A. Weston

Members of the Scientific Staff who left between January and December, 1949, to take up new appointments at home and overseas.

Chemistry Department ...	N. S. Bamji, M.Sc.
	E. T. Udall, B.A.
Plant Pathology Department	Frances M. L. Sheffield, Ph.D., M.Sc., F.L.S.
Soil Microbiology Department	Margaret P. Read, B.Sc., Ph.D.
Statistics Department ...	Pamela M. Cox, M.A.
	Monica A. Creasey, B.Sc.
	Magda Hale, cand.mag.

Soil Survey of England and Wales ... ... W. R. HEATHCOTE, B.Sc., N.D.A.
JACQUELINE P. NIGHTINGALE, B.Sc.

The following spent varying periods as temporary workers at Rothamsted during 1949.

Australia: R. S. Beckwith (Chemistry), E. M. Hutton (Plant Pathology), R. F. Williams (Botany), Gwyneth R. Wykes (Bee Research).
British West Indies: E. M. Chenery (Pedology).
Canada: R. H. E. Bradley (Plant Pathology).
Denmark: H. C. Aslyng (Physics).
East Africa: H. Birch (Physics), W. B. Tripe (Statistics), R. P. St. J. Watkin (Chemistry).
Egypt: M. H. Hassanein (Bee Research).
Holland: J. Doeksen (Entomology).
India: T. D. Mukerhea (Insecticides), M. L. Puri (Physics).
New Zealand: I. D. Blair (Soil Microbiology).
Portugal: Miss M. L. V. Borges (Plant Pathology).
South Africa: E. Pawson (Chemistry).
Tasmania: J. H. Wilson (Botany).
West Africa: J. Quartey (Statistics), A. N. C. Thomas (Field Experiments), R. Wickens (Statistics).
British Isles: D. F. Ball (Soil Survey), J. R. Butler (Pedology), A. G. Carruthers (Statistics), C. P. Cox (Statistics), P. M. Grundy (Statistics), J. Harrop (Soil Survey), J. Harrop (Biochemistry), P. N. Harvey (Statistics), E. Johnston (Soil Survey), P. T. Marshall (Insecticides), Moira McLean (Plant Pathology), R. Morley Jones (Statistics), Marjorie Myers (Plant Pathology), M. J. T. Norman (Plant Pathology), Ruth M. Powlesland (Plant Pathology), R. S. Pitcher (Nematology), D. H. Rees (Statistics), J. E. Satchell (Entomology), Joy Sheldon (Entomology), O. B. Silver (Soil Survey), Mary B. Webb (Plant Pathology), Hilary Wilton (Statistics).

Soil Survey of England and Wales

Head of Survey ... ... A. MUIR, B.Sc., PH.D.
Soil Surveyors ... ... B. W. AVERY, B.Sc.
E. CROMPTON, M.Sc.
I. L. FREEMAN, B.Sc.
C. A. H. HODGE, B.Sc.
D. W. KING, B.Sc.
W. A. MITCHELL, B.Sc.
D. A. OSMOND, M.Sc., PH.D., A.R.I.C.
J. A. POLLOK, B.AGR.SC.(New Zealand), M.F.(Minnesota).
R. S. SEALE, B.A.
C. J. TAPP, B.Sc.
Chemist ... ... H. H. LERICHE, B.Sc.
Assistant Staff ... ... Mrs. D. BAGNALL, JOY M. MILLARD.

Woburn Experimental Station

Director	Sir William G. Ogg, M.A.
Assistant Director ...	H. H. Mann, D.Sc., F.R.I.C. (Kaisar-i-Hind Gold Medal)
Chemist	T. W. Barnes, M.Sc., F.R.I.C.
Assistant for Work ...	G. Pearce

Farm Staff—

Farm Manager	J. R. Moffatt, B.Sc., N.D.A., A.I.B.A.E.
Assistant	G. Cole
Foreman	A. W. Neill
Farm Workers	Clara E. Horn, S. Beryl Horn, E. Seamark, G. Tyler, K. Wilson, J. Young
Part-time Workers ...	W. A. McCullum, A. Sibley

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director	F. G. Gregory, D.Sc., F.R.S.
Head of Department ...	F. J. Richards, M.Sc.
Scientific Staff	C. Mer, B.Sc., Ph.D., A.R.C.S., D.I.C. Helen K. Porter, D.Sc., D.I.C. W. W. Schwabe, B.Sc., A.R.C.S.
Temporary Workers ...	E. Berner, Cand.Real. A. Parkinson, M.Sc.
Assistant	Maureen Foster

The Commonwealth Bureau of Soil Science

Director ...	...	G. V. Jacks, M.A.
Consultant Director	...	Sir W. G. Ogg, M.A.
Assistant Director	...	W. D. Brind, B.Sc.
Assistants ...	...	Miss H. Scherbatoff Mrs. M. K. Milne, B.Sc. Miss K. Carver, B.Sc. Miss N. Watts, M.A.
Indexer	...	Mrs. S. Adams
Clerks	...	Cynthia M. Horn, Rita M. Perry, Doreen M. Thornett, Margaret Lobban

The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Empire by providing technical information, by promoting contact between them, and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Empire and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly 60 years. Lawes died in 1900 and Gilbert in 1901 ; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943 when the present Director Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory ; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income of which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent. of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919 ; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund ; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room, and Conference Room.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

A large new South Wing was completed in 1940, and the old chemical laboratories were reconstructed. These extensions and reconstructions have provided excellent accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments ; in addition a fine range of pot-culture houses was built. A new laboratory has also been built and equipped for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930–32 and equipped for electric light and power. Further additions were made in 1939–40, and the electricity supply has now been extended to these newer buildings.

The non-experimental part of the farm was re-organized in 1928 to meet the prevailing economic conditions, much of the land being

laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced, and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but the Station gains considerably by this closer association with the Universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934, the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted Estate were completed. The Rothamsted Trustees now own the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house, and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers, and from oversea sources.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually spreading out to the Empire and other countries. The Station regularly participates in work for the solution of agricultural problems of great importance to the Empire.

The Station offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

INTRODUCTION

Staff

A few members of the staff left during the year but several of the vacancies have been filled and a few new appointments made. Dr. F. M. L. Sheffield, cytologist in the Plant Pathology Department, who had been seconded to Zanzibar for fifteen months for work on " Sudden Death " in cloves, has accepted a permanent appointment in the East African Agriculture and Forestry Research Organization. Dr. F. M. Roberts has also gone to Zanzibar recently to work for a year on the same problem. Dr. Herbert Greene has been appointed to the new post of Adviser on Tropical and Sub-tropical soils which is being financed mainly by the Colonial Office. Dr. Greene was formerly Chief Chemist and Assistant Chief of the Research Division of the Department of Agriculture and Forests, Sudan. Since 1945 he was on the staff of F.A.O.

Mr. F. C. Bawden and Mr. N. W. Pirie were elected Fellows of the Royal Society.

The Station was represented at the following conferences : United Nations Conference on the Conservation and Utilization of Resources (U.S.A.), International Conference on Bacteriology (Belgium), International Congress on Beekeeping (Holland), Congress of French Beekeeping Associations, Meeting of the Electron Microscope Society (Holland), British Commonwealth Scientific Conference on Plant and Animal Nutrition in Relation to Soil and Climatic Factors (Australia), Fifth International Congress on Comparative Pathology (Turkey), Meetings of the Biometric Society and International Statistical Institute (Switzerland), Conference on Phosphorus and its role in Biology (France), and a Conference of the International Superphosphate Manufacturers Association (Denmark).

Dr. Muir spent several months in the United States and Canada studying soil survey methods, and the Director, in addition to attending the United Nations Conference, visited a number of research institutions in the United States and Canada.

Dr. D. M. C. MacEwan gave a course of lectures in Spain at the invitation of the Spanish Soil Institute.

During the year there were 13 long-term and 25 short-term temporary workers at the Station. Even more applications than usual had to be refused because of lack of accommodation. This is to be regretted for many of those for whom no room can be found go to other countries for their post-graduate training and, apart from that, our own workers lose a certain amount of benefit.

Visitors

The number of visitors to the Station continues to increase. The overseas visitors included the Under-Secretaries for Agriculture of the United States and Persia, a Canadian mission of agricultural scientists and administrators, the Lambert Mission on the way to Africa, and several parties of Canadian and American farmers.

Facilities were provided for various conferences, including a meeting of the Biometric Society and a meeting under the auspices of the Colloid and Biophysics Committee of the Faraday Society. Visits were paid by the Second International Congress on Crop

Protection, the Fertiliser Society, a group from the Council of the Royal Agricultural Society, and the Guild of Agricultural Journalists.

The Work of the Station

The work of the Pedology Department is concerned with the way in which rocks weather to form soils and the nature of the processes and products involved. The study of rock weathering in the Malvern Hills area has provided valuable information on changes undergone by rock minerals and some new types of clay minerals have been discovered.

An important clay mineral (montmorillonite) which occurs in soils and which has also considerable industrial use has been studied in detail. By X-ray methods its structure and the way in which the plant nutrients, such as potassium, are held on it have been determined.

Other lines of work include a study of water-logged soils, particularly in relation to the iron compounds and it has been shown that the processes are to some extent due to micro-organisms. An investigation of the distribution of the trace element molybdenum in soils has been commenced.

The Chemistry Department is engaged mainly on problems of soil fertility. Fertilizers have been in use for over a century but there are still many unsolved problems connected with their use. We know relatively little about their fate in the soil and how they are taken up and used by the plant. For experimental purposes fertilizers can now be made radio-active and their movements followed. Preliminary work with radio-phosphorus as an indicator showed that the phosphate held on the surface of some preparations of calcium phosphate was much more active than that within the crystals. Attempts are being made to control the rate of action of nitrogen and phosphate fertilizers to suit different needs. Phosphate fertilizers are being tested in pellets and also dispersed through bulky organic manures in attempts to keep them available to plants whilst protecting them from too rapid inactivation by the soil. About 80 per cent. of the phosphate applied as soluble fertilizer is not recovered in crops in the first few years but a little of the phosphate in fertilizers and farmyard manure may remain available for long periods. This is well illustrated on Hoos field at Rothamsted where plots which have received no farmyard manure or fertilizer except nitrogen since 1901 sometimes show the effects of phosphate applied annually for many years previous to that date. The dry spring of 1949 accentuated the differences in the barley crop—the farmyard manure plots and the superphosphate plots standing out very clearly during the month of May. At that time the crops on the better plots contained only two or three pounds of phosphoric acid per acre but those on the most exhausted plots had less than 0·5 lb. of phosphoric acid per acre.

Particularly for horticultural crops there is need for a slow-acting nitrogenous fertilizer to supplement the inadequate supplies of organic manures such as hoof and horn. Various new materials, including urea-formaldehyde products, are being tried. Although some of the results are promising, none of the materials has yet reached the stage for commercial production.

Fertilizer placement experiments have been continued and it has been found that heavy dressings of fertilizer placed an inch to the side of the seed damaged germination of sugar beet, mangolds and peas, but bands at 3 inches from the seed were safe. There was, however, no advantage from placed over broadcast fertilizer for sugar beet but a marked improvement for peas.

In work on the chemical nature of soil organic matter it has been shown that at least a third of the nitrogen is present as protein. The kinds and approximate amounts of amino-acids in different kinds of soil have been determined.

Field experiments in relation to soil analyses were continued and amongst other things it was found that peas receiving broadcast fertilizers responded to potassium only on soils deficient in readily soluble potassium and gave neglible responses to nitrogen and phosphorus.

Fertilizer experiments have been in progress for some time on rubber in Malaya and oil palm in Nigeria and the Belgian Congo. Recent measurements showed marked increases in tree girth and yield of latex from rubber trees manured experimentally from 1934 to 1939. The oil palm gave only small responses to fertilizers but there were slow progressive improvements from potassium fertilizer in most of the experiments and some benefit from nitrogen. Response to phosphate fertilizer occurred only on a single kind of soil at one estate.

The results over five years in investigations on nutrition problems in forest nurseries are summarized in a separate report. There were striking benefits from fertilizers on very acid soils and from so-called "partial sterilization" by steam or formalin, especially in old nurseries. The latter problem is being examined jointly with the Microbiology Department.

Soil reaction measurements at intervals from 1934 to 1947 in a chalking experiment at Tunstall in Suffolk showed that good yields of sugar beet were maintained as long as the pH of the soil was above 5·5, but it is generally advisable to keep well above that figure for sugar beet. In the same experiment, a war-time change of nitrogenous manure from sodium nitrate to ammonium sulphate without application of lime, soon led to a disastrous increase in acidity and loss of yield.

Work was continued on the forms in which manganese and other trace elements are held in soils. In a pot experiment on a fen soil low in available manganese addition of small amounts of molybdate led to the occurrence of " Marsh Spot " in peas.

Theoretical and experimental work by the Physics Department has shown that there is an upper limit to the amount of water that can be transpired by green vegetation. This amount depends only on the weather ; hence it is possible to estimate from simple weather data just how much irrigation is required. Field experiments on sugar beet in Surrey and Suffolk have strikingly demonstrated the accuracy of these estimates. Large increases in yield were obtained by employing the calculated amount of irrigation, but no further increase was obtained by doubling the amount.

The same principle has been applied in a detailed study of the water resources of the catchment area of the Suffolk Stour. Since the evaporation from this area can now be accurately estimated,

and the rainfall and river discharge are on record, it has proved possible to calculate the month to month change in ground-water storage. This kind of information is of great value to authorities responsible for water supplies.

In the six-course experiment at Rothamsted on deep and shallow ploughing, wheat and potatoes again yielded slightly better on the deep-ploughed plots and sugar beet again benefitted from deep incorporation of phosphate. It is still not clear why these effects are more consistent at Rothamsted than at other centres where similar experiments were carried out.

A study is being made of the physical processes which occur in the swelling and shrinking of clay ; this and other work will be helped by a recent improvement in our method for measuring the volume of solids, water and air as it exists in the field.

Apparatus specially designed in the Physics Department has enabled the Botany Department to study the germination of seeds in a series of constant temperature chambers in each of which the humidity is accurately controlled at a chosen level close to saturation. Under these conditions the seeds behave with remarkable consistency. One outcome of this work should be exact information about the soil moisture and temperature desirable in a seed bed.

The chemical tests applied to soil in advisory work are not wholly satisfactory, and a new approach is being made by physico-chemical methods to get a better measurement of what plant roots can take from the soil.

In the Soil Microbiology Department further work has been done on methods for estimating the numbers of micro-organisms in soil and a survey of the main groups of microbes in plots, manured with organic and inorganic manures, on Broadbalk field has been continued.

In the course of work on nitrification a pure culture was obtained of *Nitrosomonas*, an organism that produces nitrite from ammonia. Progress has also been made in the study of soil amoebæ and with mycorrhiza on crop plants. The antagonistic behaviour of certain soil micro-organisms towards the root disease fungus *Fusarium* has also been studied and it is intended to expand this study of microbial antagonism in soil.

The work on nodule bacteria and leguminous plants has been continued. This includes a survey of the areas where types of clover nodule organisms that are ineffective in fixing nitrogen are prevalent in the soil and attempts are being made to introduce effective strains. It has also been found that in certain soils effective strains of nodule bacteria tend to become ineffective. In most cases this is related to soil acidity and can be checked by liming. The problem of ineffective nodules has been found to be further complicated by the discovery that their formation can be induced not only by the strain of bacteria but also by hereditary factors in the clover plant.

The work of the Botany Department is mainly concerned with the physiology of plant growth in relation to the yield of agricultural crops. One aspect of this is the investigation of the effects of plant nutrients required in very small amounts—the so-called trace elements. The interrelation of one of these, molybdenum, with nitrogen nutrition has been studied in lettuce and red clover.

Another investigation dealt with factors affecting the rate of

uptake of nitrogen, phosphorus and potassium by roots. Work was also commenced on the uptake of mineral nutrients from solutions sprayed on the leaves of plants and it was found that appreciable amounts of nitrogen, phosphorus and potassium can be taken up in this way, but the investigation has not proceeded far enough to show how this affects subsequent growth.

In collaboration with the Physics Department, experiments have been made to define precisely the conditions of moisture supply in which germination can take place, and to study the relation between water-uptake and moisture potential.

In view of the increasing prevalence of wild oats as a weed on arable land, the biology of the two species common at Rothamsted is being investigated. In a field experiment on potatoes there was evidence that wild oat seeds had survived in the dung in a viable state or that the dung had broken the dormancy of seeds already present in the soil. These possibilities are being tested in the laboratory.

Another line work deals with the physiological effects of infection with leaf-roll virus on the potato crop. One purpose is to determine whether the intensity of the leaf symptoms depends on the conditions of growth. It was found that increased nitrogen supply and reduced light intensity both tended to mask leaf-rolling and yellowing symptoms but did not completely suppress them. The chief object of the experiment was to investigate the changes in growth due to virus infection that are responsible for the reduction in yield.

The studies on the effects of manuring on the grass and clover species in permanent pasture cut for hay were continued and also the routine observations on the weeds in the Classical fields.

The scope of the Plant Pathology Department covers both basic studies on plant viruses and fungi, and work on specific plant diseases, mainly those affecting arable crops. Improvements to the electron microscope have made it possible to determine the sizes and shapes of virus particles in the sap of infected plants, and with an improved technique the electron microscope has been used in collaboration with other departments in the study of insect cuticle and clay minerals. The transmission of viruses by aphids is being studied by using plants containing radio-active phosphorus. Work on extraction and purification of viruses continues in close association with the Biochemistry Department, and an undescribed virus on broad bean with unusual properties has been isolated. Potato tubers infected with leaf roll virus have been cured by heat treatment, and field experiments confirm the impracticability of controlling leaf roll by roguing potato crops in the South-east of England. Work on virus and fungus diseases of sugar beet continues at Rothamsted and at the field laboratory at Dunholme, Lincoln, where the desirability of raising stecklings in isolation in the North and East for sugar beet seed production, was demonstrated ; spraying with systemic insecticides or planting under a cover crop was also found to be beneficial. Laboratory studies on the survival of resting spores of the club root fungus in the soil have continued and field experiments have shown that eyespot of wheat is reduced by spraying with sulphuric acid and a spring application of nitrogenous fertilizers. A small wind tunnel has been built to study the dispersal of airborne plant disease organisms.

In the Biochemistry Department several years' work on leaf components has been completed, and a study made of the rôle of manganese in plant respiration and of the extraction of manganese from organic soils.

The Nematology Department has developed a number of new techniques for the microscopic examination of eelworms in plants, *e.g.* for measuring the vertical migration of larvæ in the soil, and for determining the proportion of living cysts of potato eelworm (*Heterodera*) in the soil. The department has acquired apparatus for collecting large quantities of eelworms from plant tissues for use in inoculation experiments. Biological studies include a sorting out of the species and strains of eelworms causing plant infestations in potato tubers, oats, bulbous iris, strawberry, and black currant. An eelworm found in roots of Sitka spruce seedlings (*Hoplolaimus uniformis*) is new to Britain. Work on root infesting eelworms has included pot studies (using clay mixed with sand, peat, compost and fertilizers) on potato plants infested with root eelworms and on the effect of adding various nematocides. Tests with the substance known as D.D. have been made in the field against potato root eelworm and sugar beet eelworm, and the effects of humidity and of repeated annual applications of D.D. to the soil are being studied. The factors which cause eelworm cysts to hatch are being studied with a view to inducing them to hatch and die before a susceptible crop is planted.

The work of the Entomology Department continues to be focussed on insect ecology and migration and the fluctuation of insect populations. Systematic trapping over a period of years has demonstrated that, in general, insects are more abundant after wet weather in summer and warm weather in winter. From this a method of forecasting insect abundance has been developed. Other methods of sampling insect and plant populations to determine relative abundance have also been studied. Records of insect migration showed no great influx into this country during 1949. A comparison of the efficiency of aerial tow-nets and suction traps operated from balloons at the R.A.F. station at Cardington has led to an improved method of studying the drift of insects in the upper air. Another side of the department's work is connected with terrestial insects, and new surveys have been started on the fauna of forest soils. Changes in the wireworm population under a variety of ley rotations are being made in connection with the new ley and arable rotation experiment on the farm. In addition tests of chemical treatment for wireworm control are in progress with the Insecticides Department. Studies on the biology of slugs have been facilitated by a method of marking individuals, and a study has been made for over 200 successive nights of the changes in a population of the grey field slug. In addition to ecological studies, the department continues to serve as the centre for identification of gall midges, and Vol. 6 of Dr. Barnes' work on " Gall Midges of Economic Importance " has now been published.

The foraging behaviour of honey bees is one of the main interests of the Bee Department, providing as it does the basis for correct management of bees for pollination and honey. Recent investigations have been summarized in Dr. C. G. Butler's book on " The Sense Physiology and Behaviour of the Honey Bee." Experiment has

shown that a bee leaving the hive without a preconceived idea will seek food in the crevices of any small coloured moving object. Prolonged observations on individually marked bees, offered a choice of experimental crops, showed that in subsequent foraging the individual bee is continually exercising both choice and memory. The technique of artificial insemination of queen bees has been developed further, and differences between colonies headed by different matings were well marked during the 1949 seasons. Other studies of bee-keeping included analysis of stores from autumn-fed syrup, the effect of winter weather on the humidity within the cluster, and work on the European foul-brood disease.

The Insecticides and Fungicides Department is concerned with the mode of action of toxic substances, and factors affecting the susceptibility of insects to toxic materials. Knowledge of these may lead to a rational choice of new toxic substances and to the more efficient use of existing insecticides and fungicides. This aim has been followed in work on the solubility of D.D.T. and rotenone in the wax layer of the insect cuticle. Studies have also been made on the susceptibility of insects at different stages in their life, on the development of resistant strains of insects and on the effect of systemic insecticides as contact and stomach poisons. Analytical work on established insecticides has continued, together with the testing of certain new materials as possible insecticides including some amides related to herculin, and synthetic materials related to pyrethrins. In response to the Colonial Insecticides Committee's request, experiments have been carried out on the persistence of D.D.T. sprayed on foliage. Analysis showed no loss of D.D.T. from films on cabbage leaves during the period of a month unless exposed to rain or short wave ultra violet light. The deposit might be attenuated, however, by expansion of the leaf. Field experiments have tested the effect of soil treatments against wireworm in the year of application and in the following season, and work has been done in collaboration with the Plant Pathology Department, on control of aphids transmitting potato viruses.

The Statistical Department has continued its work on the design and analysis of experiments and has given assistance to the other departments at Rothamsted and to many research workers in this country and the Colonies. Co-operation with the National Agricultural Advisory Service in the design and analysis of experiments has steadily increased, and is leading to more joint planning and co-ordination of experimental investigations. Assistance and advice is given both to the separate provinces, and to the Experimental Husbandry Committee of the Agricultural Improvement Council, which is responsible for the planning of experiments on the Ministry's experimental husbandry farms.

The principle sample surveys carried out during the year were the Survey of Maincrop Potatoes and the Survey of Marginal Land. The 1948 Survey of Maincrop Potatoes gave an overall yield estimate which exceeded the official estimate by 1·2 tons per acre. It was shown that late planting was associated with low yields. The Survey of Marginal Land is aimed at investigating the increase of production obtainable from this type of land and the expenditure necessary to obtain it. Other projects include a continuation of the

Survey of Fertilizer Practice and the pilot Survey of Methods of Milk Production.

The computational facilities of the department have been increased by the installation of Hollerith equipment. With these machines the data are recorded on punched cards, which can then be sorted and tabulated mechancially. This equipment is particularly suitable for analysis of certain types of survey data, but its possibilities for the more complicated types af analysis encountered in experimental work are also being explored.

At Woburn Dr. Mann has continued his work on the growing of hybrid maize, soya beans, serradella and birdsfoot trefoil and encouraging results have been obtained. Other work includes investigations into clover sickness, weed competition and nutrition of crops under very acid conditions.

The large programme of field experimantal work on the farms at Rothamsted and Woburn is dealt with fully in this report. An elaborate new ley-arable experiment has been laid down to compare the productivity of various rotations based on different types and durations of leys. There are now over 2,000 experimental plots and as in the past very efficient co-operation has been obtained from the farm manager and his staff.

PHYSICS DEPARTMENT

By R. K. Schofield

Two vacancies, one caused by the appointment of Dr. B. A. Keen to the directorship of the East African Agriculture and Forestry Research Organization and the subsequent appointment of Dr. R. K. Schofield to the headship of the department, and the other caused by the appointment of Dr. E. W. Russell to the readership in soil science at Oxford, have been filled during the year. Dr. W. C. A. Hutchinson took up his appointment in September and has since been working with Dr. H. L. Penman in the field of agricultural meteorology. Mr. W. W. Emerson started in October to take up the general lines of work related to soil cultivation developed by Dr. Russell. Mr. A. W. Taylor also joined the department in October under a special grant from the Agricultural Research Council to work directly under Dr. Schofield in a study of the chemical potentials of ions in soil. At the beginning of the year Mr. P. C. Owen transferred to the Botany Department.

Dr. M. L. Puri completed his period as a voluntary worker and obtained the Ph.D. degree of London University. Mr. H. C. Aslyng continued as a British Council Scholar, and in December was appointed Reader in Soil Science at the Royal Veterinary and Agricultural College at Copenhagen.

Dr. Schofield has served on the Joint Committee on Soils appointed jointly by the Department of Scientific and Industrial Research and the Ministry of Supply. Dr. Schofield and Dr. Penman are both members of the Technical Panel of the Land Drainage Legislation Sub-Committee of the Ministry of Agriculture's Central Advisory Water Committee. Dr. Penman served on the Council of the Royal Meteorological Society and on the Board of the Institute of Physics. During July he visited Holland and lectured to the Hydrology Commission of the Dutch T.N.O. on Rothamsted researches on evaporation.

Soil Cultivation

Deep ploughing

The loss of Dr. Russell and the transfer of Mr. Owen, who had assisted him in the deep ploughing work, have restricted operations this year to the continuation of the six-course experiment at Rothamsted.

The plots which were deep ploughed this year have now been deep ploughed three times. The soil to plough depth is now well mixed, but there is little colour difference between the shallow and deep-ploughed plots. The only noticeable difference is the greater stickiness of the soil in the deep-ploughed plots.

As in previous years, the germination and growth of sugar beet was slower on the deep-ploughed plots, but the difference had disappeared by June. At harvest, the deep-ploughed plots yielded 9·2 tons per acre of clean beet, while the shallow ploughed plots yielded 8·6 tons per acre. Deep incorporation of phosphate gave an advantage of 0·9 tons per acre. A similar effect was found each year since 1944 except 1948. As before, deep incorporation of potash was without effect.

Deep ploughing produced an increase in yield of potatoes from 5·7 to 6·7 tons per acre when potash was applied in the bouts. This can be accepted as a definite result for this site since it has occurred every year from the inception of the experiment in 1944 ; but no result of comparable consistency has yet been obtained at any outside centre.

The yield of wheat was again up by 1 cwt. per acre on the deep-ploughed plots. This advantage, though small, appears to be significant.

Agricultural Meteorology

General

In a discussion on meteorology in agriculture, organized by the Royal Meteorological Society, the department supplied an introductory survey showing the type of statistical, biological and physical problems demanding solution. An account of the 1948 irrigation experiment was given to illustrate the possibility of estimating crop transpiration from measurements of weather factors. The Agricultural Meteorology Branch of the Meteorological Office (M.O. 19) is showing an encouraging interest which will probably take a practical form during 1950 when M.O. 19 hopes to issue monthly estimates of transpiration to the provincial centres of the National Agricultural Advisory Service.

Measurements of evaporation and drainage

Day to day measurements of evaporation from open water, bare soil and turf have been continued, and in the late summer apparatus was successfully designed to obtain continuous records. The records obtained for the open water surface generally show clearly the day maximum and the night minimum, but there are some anomalies, probably caused by differential thermal expansion of instrument components. The same apparatus, used to record the fluctuation of a water-table 2ft. below a turfed sandy soil, has given some details of the slow drainage referred to in 1948. Records show quite clearly that this drainage begins about sunrise and continues until nearly midday when the direction of movement of water is reversed as the effect of transpiration begins to dominate the flow.

Taking advantage of the dry summer, new copings have been fitted to the drain-gauges of Lawes and Gilbert, and slates on one wall of the 40-inch gauge have been renewed in the hope of stopping the leak discovered in 1940. Since the operation the drainage totals (November–December) have been :—20, 6·9 inches ; 40, 6·7 inches ; 60, 6·3 inches. The drainage from the 40-inch gauge is now less than that from the 20-inch gauge, as it should be, but is still not as close to that from the 60-inch gauge as might be expected.

Control of irrigation by calculation of soil moisture deficit from meteorological data

Two centres were in use in 1949. On Mr. F. Secrett's farm at Milford there were four watering treatments :—unirrigated control (0), full irrigation at Mr. Secrett's discretion (F), and two restricted treatments (R and M) based on weather data collected on the site. Treatment R was designed to permit the building up of a water deficit of 1½ inches by the end of August, and was the same as in 1948 : treatment M was designed to permit an end-of-August

deficit of 3 inches. On the farm of Messrs. W. O. and P. O. Jolly at Kesgrave, Ipswich, there were three treatments :– O and M as at Milford, and a third (J) determined by Mr. Jolly. The summer was very dry, the May to August rain being 4·4 inches at Milford and 4·7 inches at Kesgrave, and irrigation operations were frequent. At Milford, treatment F took 13·1 inches in nine applications, R took 8·4 inches in six, and M took 6·5 inches in five ; at Kesgrave, J took 4·1 inches in two, and M took 5·6 inches in four applications.

The summer was characterized by a severe attack of virus disease, low sugar percentages, and a curious interaction of watering and nitrogen treatments, of which there were four at Milford and three at Kesgrave. As the lowest and highest were common to both centres, values for these are given in the following table :– –

Yield of sugar (*cwt. per acre*)

Treatment		O	M	R	F	O	J	M
Irrigation (I)	...	0	6·5	8·5	13	0	4	5·5
Rain + I. (in.)	...	4·5	11	13	17·5	4·5	8·5	10
Yield 0·4 cwt.N/a		36·0	44·3	44·2	44·1	30·2	49·8	53·6
Yield 1·3 cwt.N/a		32·1	40·8	43·0	39·2	31·4	42·7	44·3

The results show the benefit of irrigation in a dry summer even for a deep-rooted crop like sugar beet. The benefit was greatest for the treatment based on weather data.

Rainfall, evaporation and run-off for the Stour Catchment

The Land Drainage Legislation Sub-committee of the Central Advisory Water Committee of the Ministry of Agriculture is gathering information through its technical Panel on the effects of land drainage on the flow of rivers. As a part of this inquiry Dr. Penman has examined the records of rainfall and run-off for the Stour Catchment over the period 1933 to 1948. On calculating the evaporation from mean values of meteorological observations taken at nearby stations he has accounted very satisfactorily for the difference between rainfall and run-off and for the changes in ground-water storage as exhibited by well records. Land drainage has been extensively carried out in this area since 1939 but it has been without discernible effect on the evaporation, and so cannot be said to have influenced the total amount of water discharged into the Stour.

Heat balance of the soil

Evaporation requires latent heat and this heat is a major item in the balance sheet of incoming and outgoing energy. The data for the Stour Catchment have been studied from this angle also. The results, which can be considered to apply to much of Southern England, show how incoming solar radiation is used up month by month throughout the year. Before and after the midsummer peak about half of the energy is used in evaporation (transpiration), and only small amounts are used in warming of the soil and the air. Throughout the year there is a fairly steady outward flow of long-wave radiation which, in winter, draws its energy from the soil and air.

In preparation for more detailed studies of heat flow in the soil, a set of resistance thermometers linked with automatic recording apparatus have been installed, which will measure the soil temperature down to 6 feet. It is hoped that the data thus accumulated will help to unravel the complex physics of radiation frosts.

Micrometeorology

The thermistor bridge, described in 1948, has been greatly used by Dr. Broadbent to obtain records of temperature and humidity profiles, and of wind speed among potato crops of varied spacing over dry and wet soil.

LABORATORY WORK

Measurement of the volumes of solids, water and air in soil clods

It has been necessary to make further minor modifications in the method introduced by Russell for measuring the volumes of solids, water and air in soil clods. Using the original technique it is impossible to prevent evaporation of water from the clod during the series of manipulations, and it is difficult to estimate the errors this may cause. A redesign of the apparatus practically eliminates this source of error. Further tests will be carried out.

Vapour pressure of aqueous solutions

It has been difficult to decide which set of measurements to take as the standard for accurate evaluation of aqueous vapour pressures. Between 98 per cent. relative vapour pressure and saturation—the range of greatest significance in soil and plant studies—the values for solutions of NaCl and KCl should be obtained very accurately from measurements of the E.M.F. of concentration cells. Direct vapour pressure measurements have not yet been made with sufficient accuracy to serve as a check, but there are numerous published results giving the concentrations of isopiestic solutions with high precision. A comparison shows that either the E.M.F. values for NaCl or those for KCl must be less exact than their internal consistency would lead one to expect, and a search is being made for a criterion that will reveal which set of data is the more reliable.

Provisionally the E.M.F. measurements for NaCl are being used in preference to those for KCl, and tables have been drawn up relating the molality of NaCl solutions to vertical height in metres, which express the amount by which the potential of water in the solution is lower than that of pure water at the same temperature. These tables are being used in the study of environmental factors influencing seed germination which the Botany Department is carrying out with the co-operation of the Physics Department. Careful consideration has been given to the design of the temperature regulators of the double thermostat tank used for this work. The apparatus is very satisfactory in that no short period temperature fluctuation that would disturb the relative vapour pressure of the seeds' environment can be detected with a thermometer sensitive to 0·001°C.

Thickness of water films

An apparatus for the measurement of the thickness of water films on mica was set up and some preliminary work carried out. Following the Russian work, a hydrogen bubble is pressed against a mica plate immersed in a solution of an electrolyte. The thickness of the phase film over the area of "contact" of the bubble is estimated by comparison of its light transmission with that of the surrounding Newton ring system. The comparison can be made directly by means of a suitable light-sensitive cell mounted on a travelling microscope. Owing to the lack of a suitable microscope

the method now being tried is a photographic one, which should at least have one advantage in giving a permanent record of each experiment. The necessary comparisons of the light intensities can be found by using a micro-photometer, and the bubble size by direct measurements on the photographic plate.

Thermodynamic potentials of soil constituents

Considerable progress has been made in the development of methods for determining the thermodynamic potentials of nutrients and other substances in soils. Where, as in soil, we are dealing with electrically charged particles it is difficult to define the potential of any single ionic constituent. We can ,however, define the difference of potential between electrically equivalent quantities of two cationic or of two anionic components, or the sum of the potentials of electrically equivalent quantities of two components, one cationic and the other anionic. Thus the pH of a soil suspension is not, in itself, a characteristic of the soil, inasmuch as it depends on the salt concentration, whether set up merely as a consequence of shaking up a soil sample in distilled water, or deliberately produced by the addition of $CaCl_2$. On the other hand, the difference of potential expressed by $pH - \frac{1}{2}pCa$ has a definite value for a soil sample independent of salt concentration up to about N/50. We expect this principle to apply to any pair of cations, and one of the tasks ahead is to demonstrate this.

Particular attention has been paid to phosphate, and it has been found that the potential sum represented by $\frac{1}{2}pCa + pH_2PO_4$ is independent of $CaCl_2$ concentration up to 0·01 molar. Values so far obtained range from 5·5 for soils liberally dressed with superphosphate to 8·5 for soils on which all crops fail unless phosphate is applied. Fortunately these potentials can be rapidly determined, and it is hoped that they will provide a surer basis for advice on phosphate manuring than any of the conventional methods hitherto employed.

CHEMISTRY DEPARTMENT

By E. M. Crowther

Fertilizer Experiments

Much of the work of the department is concerned with the analysis of problems of soil fertility and manuring by combining investigations in the laboratory, pot culture house and field experiments. Manurial experiments on sugar beet have been conducted in collaboration with the agriculturists of the sugar beet factories at some twenty centres each year since 1933, and the responses to fertilizers have been compared with those of laboratory examinations of soil samples taken before the fertilizers were applied to the plots. In many of the years leaf and root samples have been examined at the end of the growing season. This series of field experiments and an additional one on alternative forms of nitrogen fertilizers were continued in 1949. Arrangements for future experiments on this crop are under review.

In a much smaller series of experiments in co-operation with the staff of the Home Grown Threshed Peas Joint Committee and the National Agricultural Advisory Service from 1946 to 1949, the average responses to nitrogen and phosphate fertilizers were trivial and those to potassium fertilizer were profitable only on soils deficient in readily soluble potassium. Thus, grouping the experimental centres by soil analyses made by a rapid method in which the soil was extracted for one minute with 0·3 N.HCl the average responses to potassium fertilizer were :

	Readily soluble potassium in soil mg. K_2O%	No. of experiments	cwt. additional peas per acre from 2 cwt. muriate of potash per acre
Low ...	0–6	7	2·1
Medium ...	7–8	5	0·3
High ...	Over 8	13	–0·1

In these experiments the fertilizers were applied broadcast shortly before sowing. With this method of application there is little justification for manuring peas, except where acute potassium deficiency is suspected. It will be shown in a later section of this report that suitably placed fertilizers may give good responses where broadcast fertilizers fail.

For many years manurial experiments designed and analysed at Rothamsted have been carried out on tropical plantation crops. In one series started on newly budded rubber in Malaya in 1934 and supervised by Dr. W. B. Haines, growth in girth showed marked and very rapid responses to ammonium sulphate and mineral phosphate but not to sulphate of potash. The trees with nitrogen and phosphate were ready for tapping many months before the untreated trees. In 1948 and 1949 it was possible to remeasure the girths of the trees and to obtain several rounds of sample-tappings from two of the experiments, which had, of course, had no further treatment or attention after 1940. In one experiment the number of tappable trees was least on plots which had received no nitrogen or phosphate from 1934 ; there was a significant increase in the yield of latex from the earlier nitrogen dressings on plots which had also

received phosphate. In another experiment on a different estate the numbers of tappable trees and the yields of latex per tree tapped were higher on plots which had received mineral phosphate from 1934 to 1940. These reults provide an interesting example of the way in which suitable manuring in the early stages of the growth of trees may show improvements over long periods.

In experiments on both mature and newly planted oil palm started in 1940 in two estates in Nigeria and one in the Belgian Congo, the effects of nitrogen, phosphate and potassium fertilizers were small and irregular in the early years, partly because it was not possible to maintain regular manurial dressings during the war. Progressive changes with time showed, however, moderate improvements from potassium fertilizer in several experiments and small improvements from nitrogen. In most of the experiments, including those started at the time of planting, there were negligible effects from phosphate fertilizers. Significant improvements in yield from phosphate were obtained only on a single kind of soil at one of the three estates.

Since 1945 several members of the department have co-operated with the Research Division of the Forestry Commission in investigations on nutrition problems in forest nurseries. A general summary of the principal findings is given in a separate section of this Report.

Phosphate fertilizers

It is well known that superphosphate may have relatively small residual effects on certain kinds of soil, especially very acid ones, and it is often assumed that other kinds of phosphate fertilizer are therefore to be preferred on these soils. Although we have not yet been able to make long-term experiments to measure the residual value of different kinds of phosphate fertilizers on acid soils, we have had a number of experiments in which superphosphate has given excellent results on acid soils in the year of application. Of the alternative kinds of fertilizer tested only silicophosphate has given higher yields and phosphate recoveries than superphosphate, and the superiority was very small. Very good results have been obtained from superphosphate in forest nurseries and forests, even on acid soils, and sometimes the advantage from superphosphate has been outstanding in comparison with Bessemer basic slag and ground mineral phosphate. These results are consistent with the view that a special merit of water-soluble phosphate applied at or shortly before sowing is to stimulate early root growth and establishment, which may be of the greatest importance in dry springs. This feature of soluble phosphate fertilizers can be fully exploited where safe methods can be found for placing the fertilizer close to the seed. It may then become possible to rely on moderate annual applications instead of attempting to build up large reserves in the soil. There are other conditions in which it may be desirable to maintain a continued supply of available phosphate over longer periods. Some possible methods are being tested. Newly planted forest trees have received compound fertilizer (5%N, 10% P_2O_5, 5% K_2O) compressed into one-ounce pellets, one on each side of the tree. Somewhat unexpectedly it was found that during the drought of 1949 over 90 per cent of the nitrogen, phosphorus and potassium had diffused out of the pellets after a few months. The pellets appeared unchanged but they

retained little but gypsum. Although these observations suggest that the pellets may not act slowly enough for the purpose intended, the rapid outward diffusion of the soluble salts may reassure farmers who doubt the activity of granular fertilizers when they find apparently unaltered granules at the end of a season. To slow down the rate of action of phosphate granules or pellets it may be necessary to select relatively insoluble ingredients. Another method under test is to mix superphosphate with bulky organic materials, such as chaffed green bracken, with the object of producing a less soluble calcium phosphate within the pieces of organic matter. Such material might remain accessible to plant roots but be brought only slowly into contact with the soil.

Long-term residual effects of superphosphate and farmyard manure

An account is given in the Field Experiments section of this Report of the striking residual effects shown in the Hoos Field Exhaustion Land in the barley crop of 1949. Plots which had received either superphosphate or farmyard manure for many years before 1901 but none since gave fair barley crops whilst those which had received no phosphate in the wheat and potato experiments before 1901 showed most acute symptoms of phosphate deficiency. Plant samples taken on 14th May 1949 gave the following yields and analyses.

Treatment before 1901	Dry matter cwt. per acre	P_2O_5% of dry matter	P_2O_5 in crop cwts. per acre
No phosphate ...	1·1	0·32	0·004
Superphosphate ...	3·4	0·48	0·016
Farmyard manure ...	5·4	0·57	0·031

The fact that the phosphoric acid percentage increased regularly with the yield suggested that available phosphate was the principal controlling factor. The extra phosphate content on the better plots with manurial residues amounted, however, only to from 1 to 3 lb. P_2O_5 per acre. Analyses for readily soluble soil phosphate showed differences over a tenfold range. The yields of barley followed the soil analyses quite well, except that plots without potassium before 1901 gave poorer plants for a given level of soil phosphate than those with either farmyard manure or potassium sulphate before 1901. This shows a residual benefit from potassium fertilizer. Samples taken on the same day from the permanent barley plots in the same field gave about 0·6% P_2O_5 in the dry matter for plots without superphosphate and from 0·8 to 1·0% P_2O_5 in the dry matter from plots with superphosphate every year. Another experiment in the same field shows that the residual effect of superphosphate in this slightly calcareous soil falls off only very slowly from the second to the fifth year after application. The observations on the exhaustion land show that a small fraction of added phosphate and potassium may remain available for many years.

Rate of action of nitrogenous fertilisers

Crop residues, farmyard manure and composts may liberate available nitrogen over many months, whilst most nitrogen fertilizers, including such organic materials as dried blood and crushed hoof, act very rapidly. This may allow serious losses of nitrate by leaching, and in very acid soils even ammonium may be lost. For many crops growth might be steadier and manurial practice

simplified if slowly acting nitrogen fertilizers could be prepared. Among the waste products we have tested the best results have been obtained from a plastic waste derived from formalized casein. Even slower and more prolonged action has been obtained in pots from crushed hoof which was inactivated by treatment with formaldehyde. A number of synthetic products, including several batches of urea-formaldehyde condensation products, have been tested. The rates of action have been assessed from pot experiments on repeatedly cut perennial ryegrass, the effects of dressings incorporated in the soil at the beginning of the experiment being compared with graded dressings of urea applied as top-dressings in factorial combinations on three occasions. In this way it is possible to assess the amount of available nitrogen supplied at different stages in the growth of the crop and to reduce the disturbance from the delayed response of the crop to nitrogen absorbed at an earlier stage. The absolute amounts of slowly available nitrogen obtained from any of the forms tested was small by comparison with the amounts of rapidly available nitrogen. No material tested gave results comparable with the same total amount of nitrogen applied in repeated dressings of a soluble form. For a given amount of early growth the amount of late growth increased in the order: urea, hoof, urea-formaldehyde products, formalized casein, formalized hoof. The results confirmed American findings that for urea-formaldehyde products both the early and the late supplies of available nitrogen increased with a conventional estimate of the "soluble nitrogen" in the product. It appears that much more experimental work will be required on the production and testing of ureaformaldehyde products before commercially useful materials can be prepared.

Fertilizer placement

Experiments comparing fertilizer placed near the seed with that broadcast were carried out in 1948 on sugar beet, mangolds and threshed peas. Two methods of broadcasting fertilizer were tested. Early dressings applied after ploughing were worked deeply into the soil by the cultivations given in preparing the seedbed. Late dressings were applied to the seedbed and were harrowed in shallowly. Fertilizer was placed three inches below the soil surface in bands at one inch and at three inches to the side of the seed.

Heavy dressings placed one inch to the side of the seed damaged the germination of sugar beet, mangolds and peas; bands three inches to the side of the seed were safe. Complete dressings of fertilizer for row crops should be placed not less than two inches to the side of the seed.

National Compound Fertilizer No. 2 (9%N, 7·5% P_2O_5, 4·5% K_2O) gave similar yields of sugar beet and mangolds when broadcast and when placed in bands at safe distances to the side of the seed. For such crops grown on average soils there is no advantage from placing fertilizer beside the seed except that the labour involved in applying the fertilizer separately is saved. Further experiments in 1949 have compared a phosphate-potash fertilizer (15% P_2O_5, 13% K_2O) broadcast and placed in a band two inches to the side of the seed. Preliminary results show that placed and broadcast fertilizer have again given similar yields.

Phosphate-potash fertilizer (10% P_2O_5, 20% K_2O) was applied in experiments on threshed peas in 1948. Bands placed at the side of the seed gave consistently higher yields than the same quantity of fertilizer broadcast. Early dressings worked deeply into the soil gave slightly higher yields than dressings broadcast on the seedbed. In 1949 a phosphate-potash fertilizer (15% P_2O_5, 13% K_2O) applied three inches below the soil surface and two inches to the side of the seed gave consistently higher yields than the same quantity of broadcast fertilizer. The average *extra* yields of threshed peas from placing as compared with broadcasting 4·5 cwt. of fertilizer per acre in experiments over three years were

		extra yield of peas cwt. per acre
1947	3 experiments	2·8
1948	5 experiments	2·2
1949	6 experiments	1·5

One experiment in 1949 on peas picked green for canning gave higher yields from placing than from broadcasting fertilizer. Placement was also superior to broadcasting in three experiments on spring beans.

Radioactive Tracers

During 1949 apparatus was assembled and standardized for using radiotracers in soil and fertilizer investigations. Work elsewhere on the uptake of nutrients from soils and added fertilizers had revealed some uncertainties in the interpretation of results of experiments with radiotracers as indicators through possible damage to plants by radiation and also through isotopic exchange between soil phosphate and added phosphate. It was therefore decided to begin by examining isotopic exchange phenomena in simpler systems before proceeding to experiments on soils and plants. With anion exchange resins and preparations of basic calcium phosphate exchange with added phosphate proceeded very rapidly, equilibria being attained within a day or so. With coarsely crystalline fluorapatite the exchange, though much slower, was still appreciable. Estimates of the apparent surface for exchange were about ten times that calculated from the size of the crystals. Measurements of the speed and extent of isotopic exchange distinguish sharply between coarsely and finely crystallized materials, and thus offer means for comparing the surface activities of preparations of calcium phosphates and other materials likely to be involved in the behaviour of fertilizer products in soils.

Soil Organic Matter

Earlier work on the extraction of organic matter from soils and the nature of the organic nitrogen in soils was prepared for publication. It had been shown that at least one-third of the organic nitrogen of soils was in the form of protein. The amino-acid composition of soil hydrolysates has been studied by the paper chromatography technique and the following amino-acids identified; aspartic and glutamic acids, serine, threonine, glycine, alanine, valine, leucine, isoleucine, proline, hydroxproline, arginine, histidine, lysine, phenylalanine, tyrosine, β-alanine, α-amino-n-butyric acid and γ-aminobutyric acid. In addition, glucosamine and an

unidentified substance giving a purple colour with ninhydrin have been detected. Preliminary investigations suggest that the latter is αε-diaminopimelic acid. Results so far obtained indicate that the amino-acid composition of the protein material in different soils is substantially the same. No free amino-acids have been detected in any of the soils studied.

The paper chromatography technique has also been employed in preliminary work on the nitrogen metabolism of soil and in a comparison of the amino-acid composition of fresh and rotted straws.

Manganese and Copper in Soils

In pot experiments on a fen soil low in total manganese the addition of small amounts of molybdate to the soil gave a considerable proportion of peas showing "Marsh Spot" under conditions in which untreated soil gave healthy peas. In a later experiment on a mineral soil low in total manganese healthy peas were obtained whether or not molybdate was added. It is possible that the effect of molybdate on the fen soil involved an increase in the ratio of soluble nitrogen to manganese in the plant, as earlier experiments had shown that "Marsh Spot" could be made more severe by injecting simple nitrogen compounds into plants. In pot experiments copper and manganese added on the surface of fen soils were held almost completely in the top centimetre or so of the soil. These results illustrate the firmness with which copper and manganese are retained in organic soils.

Neutral pyrophosphate extracts of organic soils when diluted with additional neutral pyrophosphate dissolve relatively large quantities of manganese when treated with manganese dioxide. In one case the neutral pyrophosphate extract corresponding to 1 g. of a fen soil dissolved 0·1 g. of manganese.

Soil Reaction

In an experiment on different amounts of chalk on a very acid light sandy soil at Tunstall, East Sussex, quite small dressings (1 ton $CaCO_3$ per acre) sufficed to give good crops of sugar beet so long as the nitrogen dressings were in the form of sodium nitrate. From 1941 onwards the sodium nitrate was replaced by ammonium sulphate and the yields of sugar beet and the pH values of the surface soils rapidly fell. Over the whole period of the experiment good yields were obtained on plots with surface pH values of 5·5 and over. In the early years the sugar beet failed when the surface soil had pH values around 5·0 but towards the end of the experiment there were moderate crops on plots with these very low pH values. The difference is due to the circumstances that in the early years the pH values of subsoils were low but in the later years the subsoils on the limed plots had relatively high pH values and exchangeable calcium contents through the leaching of calcium from the added chalk.

For some purposes, *e.g.* for growing lime-sensitive crops or for increasing the availability of certain micronutrients, it may be necessary to acidify field soils. A number of experiments have been made with such materials as sulphuric acid, aluminium sulphate, sulphur and ammonium sulphate. For the first year or so after treatment there is a risk of damage to certain sensitive species from the residues of some of these materials, especially in dry seasons.

Experiments are in progress to discover what interval must be allowed for safety under various conditions.

General

Papers and reports dealing with the results of field experiments on crop rotations and manuring were prepared for two international conferences and for other discussions on fertilizer policy.

Analytical

A large amount of time was devoted during the year to transferring the vast collection of samples of soils and crops built up over a century from the old sample house near the laboratory to a new one in the outbuildings to the Rothamsted Manor.

As the first crops were cut in the new arable-ley rotation experiments at Rothamsted much time was devoted to devising satisfactory methods for handling and analysing the samples. Complications frequently arise in newly established leys and under some conditions in old permanent grass through the inclusion of appreciable quantities of soil in samples cut by a rotary scythe.

For periodic analyses of field and pot soils satisfactory results were obtained by rapid methods of analysis for nitrate by a brucine colorimetric test and for ammonia by nesslerising the ammonia collected in a Conway diffusion unit.

In the colorimetric determination of phosphorus by the stannous chloride-ammonium molybdate method, the solution containing phosphorus as orthophosphate must be free from iron. The tedious separation of iron by precipitating and filtering may be avoided by using Zeokarb 216, a cation exchange resin. Ferric iron is retained by the exchange material whilst the phosphate passes through completely and may be determined colorimetrically in the leachate without further treatment.

Low results in the micro-determination of fluorine by titrating with thorium nitrate may be caused by some of the fluorine being present as fluosilicate ion, SiF_6, after separation of fluorine from interfering ions by distillation from sulphuric or perchloric acid. The fluosilicate ion does not form an unionized compound with thorium as fluoride does. It was found that this error could be avoided by carrying out the titration in a 50 per cent. alcoholic system buffered at pH 5·3 using gallocyanine indicator.

PEDOLOGY DEPARTMENT

By A. Muir

Weathering of Rocks and Minerals

During the year work was continued on the rocks and soils of the Malvern Hills. In the case of the soil derived from biotitite it has been shown that the clay mineral present represents a mixed chlorite-vermiculite structure. This is the first report of such a mineral type forming an essential part of the colloid fraction of a soil, although the existence of such a structure had been suggested, and later verified for larger crystals by Barshad in California. In the Malvern soil (of low pH) the predominantly chloritic material of the weathered rock passes into a vericulitic material in the soil, the transition taking place both in the coarse flakes of weathered biotite and in the clay, although the process does not seem to be quite the same for the two types of material. An interesting point is that even in the upper soil horizon there was very little true vermiculite present, most of it existing in mixed-layer minerals. On the basis of these observations it is suggested that there is a complete range of intermediate minerals between chlorite and vermiculite and an explanation of the possible means of transition can be given.

Clay Mineral Studies

A start has been made in a survey of the clay mineralogy of a large number of sedimentary rocks from various parts of England and Wales. In particular, several samples of Keuper Marl deposits have been examined, and the general presence of the chloritic components mentioned in last year's report has been confirmed. (See abstracts under Stephen and MacEwan, 1950). Analyses have also been made of soil clays from the Middle East and East Africa.

In connection with the expansion of X-ray diffraction work in the department, an experimental design for a gas X-ray set suitable for mineralogical work has been evolved and this is now being constructed.

Work on surface and interlamellar absorption by clay minerals and related substances, from solution, has been commenced by Mr. R. Greene-Kelly under a special A.R.C. grant.

Absorption complexes of α-zinc hydroxide

In extending the work on this subject it has been found that replacement of absorbed Naphthol Yellow anions can be effected by inorganic and aromatic anions. The kinetics of such exchange is specific for each anion. For halide anions, the rate of replacement follows the series $F^- > Cl^- >> Br^-$. The rate of replacement with I– is imperceptible (if there is any) even at elevated temperatures (70°C). Only the chloride exchange experiment resulted in the conversion of the primary dye complex into a flake of structure similar to the α–form of $Zn(OH)_2$ from $ZnCl_2$ solutions.

Anion exchange with *other* dyestuffs proved of greater interest. Three dyestuffs, of which two could not be induced to form primary complexes with α–$Zn(OH)_2$ due to low solubility or high molecular weight, were interacted with a flake of the primary complex. In all cases, the change in the basal spacings was consistent with a replace-

ment of naphthol yellow anions; in two cases the observed spacings could be quantitatively predicted from a calculation of the areas of the dyestuffs molecules. This is, so far, the only proof (indirect as it is) of the uptake of dyestuff in layers. All attempts to induce preferred orientation in the primary naphthol yellow complex (including pressure treatment of some hundred atmospheres) were unsuccessful, and direct proof of layer absorption of dyestuffs by X-ray methods could not be obtained.

The conditions necessary for the production of the expanding type of the naphthol yellow primary complex mentioned in the Annual Report for 1948 were investigated; dyestuff concentration during precipitation and the extent of washing were found to be the critical factors.

Subsequently, a host of complexes has been prepared with different organic anions with a view to ascertaining what particular structural characteristics in the absorbed organic anions encourage the formation of stable well-oriented primary complexes. The occurrence of substituent nitro- or nitroso- groups, preferably in ortho- or para- configuration with -OH groups, seems to be conducive to their formation, suggesting a modified chelate bonding on the zinc hydroxide surfaces. Highly oriented and crystalline precipitates can be formed in this way, the effect being heightened by precipitation at higher temperatures. The temperature effect is less marked on complexes with larger organic anions or molecules containing a greater number of NO_2 groups.

Analyses of X-ray powder diagrams and uni-dimensional Fourier analyses of (001) reflections in oriented flake diagrams of some of these complexes reveals the uptake of the organic anions in layers. The Fourier analyses suggest the formation of $Zn(OH)_2$ layers with three sheets of (OH) groups in each layer rather than two as in the brucite structure.

Location of adsorbed ions and molecules on montmorillonite

This work has now been completed, and the resultant Fourier curves show two interesting points. Firstly, the exchangeable cations in the montmorillonite-glycerol complex take up a position midway between the inorganic layers of the mineral. Secondly, the structure of the inorganic layers of montmorillonite is in accordance with that proposed by Hofmann rather than that suggested by Edelman.

A similar study is now being made with hectorite, a trioctahedral montmorillonoid. This is not yet complete, but the Fourier curves confirm the Hofmann structure for the montmorillonoids.

Interstratified clay minerals

Work in the department and elsewhere has shown that randomly interstratified clay minerals are fairly common in soil clays. To facilitate their identification the intensity and distribution of scattered X-radiation from a number of types has been calculated using the formula derived by Hendricks and Teller (J. Chem. Phys., 1942, **10**, 147). The types chosen were those most likely to be encountered in practice and the results will prove of great value.

Spectrographic Work

Work has begun on the investigation of the Mo content of soils, and working curves for its determination have been derived. It is

already well known that certain soils derived from the lower Lias have abnormally high Mo contents and it is hoped that some information will be obtained on the general distribution of Mo in different types of soil. The Mo content of most soils appears to be of the order of a few parts per million only, which is near the spectroscopic limit of detection.

Some analyses for Mo have been done for the Botany Department on samples of lettuce from water culture experiments.

The routine analysis by the Lundegardh method has been going satisfactorily. Some 400 samples, mainly soils sent in by the soil surveyors, have been analysed for the exchangeable ions, K, Na, Ca, Mg, Sr and Mn. Some determinations of Mn have also been carried out on wild oat samples for the Botany Department.

Gleying in Soils

The study of artificially produced gleying on incubating soil material in sugar media has been continued. Determinations have been made of the residual sugar and ferrous iron contents of the fermentation solutions, as measures of the rate of microbial growth and of the gleying reaction respectively. In such experiments not only the sugar, but also the iron curves, are of sigmoid form, suggesting a microbial process as the rate-determining factor in the process of gleying.

Experiments have been made using grass or leaves in place of dextrose as the source of energy, thereby simulating soil conditions more closely. It has been found that under these conditions the results are comparable with those obtained in sugar fermentations, both in the extent and rapidity of the process.

The aliphatic acids produced in the sugar fermentations form complexes with ferric iron. As the published data on the composition of these complexes do not agree in certain instances, a number of redeterminations have been attempted by potentiometric and conductrimetric titrations—the methods used in general, by previous investigators. As a solution of a ferric salt is strongly hydrolyzed and consequently highly acid, it has generally been found necessary to employ solutions of the sodium salts of the organic acids in order to obtain a pH value sufficiently high to allow complex formation to occur. Thus during titration, the pH varies between wide limits, often by as much as 4 or 5 units. In addition to the direct effect of the pH on the quantity being measured, the relationship between the pH and the stability of the particular complex must be considered. Thus if during the titration of the sodium salt with a ferric solution, the pH falls to a value at which appreciable dissociation of the complex commences, the concentration of $Fe^{\cdot\cdot}$ in the solution will increase, regardless of any consideration of the stoichiometric end-point of the complex formation. Hence the ratio $Fe^{\cdot\cdot}$/organic acid, as determined by the point of inflection in the experimental titration curve, will be a function of the initial pH of the solution titrated, the pH of the titrant, and the dissociation of the complex as a function of pH, as well as of the theoretical composition of the complex. Should the complex be stable at low pH values, only the last factor will be operative. This is the probable explanation for the agreement of different workers on some systems,

while the preceding factors, no doubt, are the cause of the non-accordance of results for other, less stable systems.

Bio-geochemistry of Aluminium

Aluminium accumulators were found to be far more widespread than was hitherto known. Vast areas of tropical rain-forests and secondary growth contain a large proportion—often pure stands—of Al-accumulating trees and shrubs. The effect of a continuous fall of leaves rich in aluminium on tropical soil formation is being studied. A preliminary analysis of 40 leaf samples from the Caucasus which were supposed to be aluminium rich did not reveal abnormal amounts of this element. Only a small part of the comparatively high total of the aluminium content of topsoils in this region can therefore be ascribed to present-day vegetation.

Since the tea-bush is the best known aluminium plant it was chosen for detailed study. From the analyses of over 300 samples from Ceylon and East Africa, the following points have emerged :—

1. The Al content is very low in the growing parts but increases continuously with age, rising to more than 17,000 p.p.m. from less than 100 p.p.m.
2. Phosphorus uptake is normal in a healthy tea-bush and its mobility is unaffected by the aluminium.
3. The tea-bush probably holds the record for high Mn content without toxicity symptoms ; healthy leaves may contain as much as 10,000 p.p,m. Mn. It is conceivable that the presence of similar amounts of Al protect the leaf tissue from Mn damage which would certainly occur in plants which are not aluminium-accumulators.

SOIL MICROBIOLOGY DEPARTMENT

By H. G. Thornton

Work on the Soil Micropopulation

Relation of microscope to plate counts of microorganisms in soil

The development of a statistically satisfactory method for counting bacterial cells in soil by microscope counts has raised an issue of fundamental importance to soil microbiology, owing to the finding that microscope counts give estimated numbers many times higher than plate counts, which suggests the possibility that only a small fraction of the soil's bacterial flora has been studied by platings and by isolations from plate colonies. The application of this microscope method to the estimation of fungal mycelium in soil provides the only existing method of assessing the quantity of fungal material present in soil as mycelium, so that here also a comparison of such estimates with plate counts becomes important.

With regard to bacteria it seemed desirable in the first instance to obtain data as to the ratios of microscope to plate counts from a wide range of soils and also from samples taken at intervals from differently manured plots. The help of the National Agricultural Advisory Service bacteriologists has been obtained in this survey from different soil types and the results which they are obtaining are being received and collated.

Counts of microorganisms from Broadbalk plots

As mentioned in the previous report, counts of various groups of microorganisms were made from samples taken from some of the Broadbalk plots during 1948. The objects of this survey were not only to compare microscope and plate counts but also to assess by present day methods the effects of organic and artificial manuring on the soil micropopulation.

The microscope counts of bacterial cells and actinomycete spores were significantly correlated with soil moisture and with numbers of actinomycete colonies appearing on plates, but not with bacterial colonies. On Plot 2 (F.Y.M.) the total length of fungal mycelium found by microscopic examination was significantly correlated with numbers of fungal colonies on plots.

Microscope counts of bacterial cells and actinomycete spores, and plate counts of bacterial and actinomycete colonies both gave higher numbers on Plot 2 (F.Y.M.) than those obtained from Plot 3 (unmanured) or Plot 7 (complete minerals and ammonium suplhate) which were about equal. Manurial treatment did not significantly affect the total lengths of mycelium found by microscopic examination, but both Plots 2 and 7 gave higher plate counts of fungi than did the unmanured Plot 3. The numbers of amoebæ found in Plots 2 and 7 were not significantly different but both were higher than those found in Plot 3.

This survey of Broadbalk plots was carried out by a team of workers (Dr. Janet Mollison, Dr. B. N. Singh, Mr. P. C. T. Jones and Mr. F. A. Skinner).

Partial sterilization

A field experiment on the effect of partial sterilization in a nursery bed for Sitka Spruce was carried out at Ampthill, Bedfordshire, by the Chemistry Department during 1949. The Soil Microbiology Department made a study of the micropopulation of soil samples taken from certain of these plots at intervals throughout the season. The results are not yet complete but indicate striking and persistent changes following the partial sterilization. (Dr. Janet Mollison, Miss Lettice Crump, Dr. B. N. Singh and Mr. P. C. T. Jones have been engaged on this survey).

Antibiotic actinomycetes

The possibility of using microorganisms that produce antibiotic secretions to control root disease fungi is being studied by Mr. F. A. Skinner in the special case of actinomycetes antibiotic against the fungus *Fusarium*. When such actinomycetes are grown with the fungus on plates of washed agar and mineral salts alone growth occurs but there is usually little or no evidence of antibiotic action, such action is however induced by the addition of glucose even in quite low concentrations. Antibiotic activity in agar is markedly reduced by the addition of charcoal or bentonite to the agar but not by the addition of Kaolin.

Some actinomycetes that are antagonistic to *Fusarium* on agar have not been found to produce antibiotic secretions in liquid culture even when aerated.

In this work it has become important to be able to measure growth of both the fungus and the actinomycete mycelium in liquid culture. This can be done in the case of the fungus by microscope counts and measurements of fragmented mycelium, but such a method is unsuited to the finer actinomycete hyphæ. Similarly we need a method for the comparative estimate of actinomycete mycelium and spores in soil. The effect of shaking suspensions of mycelium with sand showed a relationship between time of shaking and numbers of colonies found on subsequent platings, whereas with a suspension of spores time of shaking did not affect the count.

Resin attacking organisms

In his work on the biological decomposition of resins tested for the making of temporary roads Mr. P. C. T. Jones isolated a number of bacteria and fungi that could attack resins. The characters of these organisms and their action on resins has been further studied with a view to publishing descriptions of them.

Nitrification

The importance of nitrification in soil makes it important to find out what organisms are important in carrying out this process in soil. In view of recent work on the biochemistry of nitrification in soil it is important to make fresh study of the physiology of Nitrosomonas and Nitrobacter to see whether their behaviour agrees with that postulated for the nitrifying flora of soil. By a modified process, Dr. Jane Meiklejohn obtained and has described a pure culture of Nitrosomonas and found that this oxidized ammonia as rapidly as did a crude culture containing the commonly occurring contaminants. This makes it unlikely that the latter act symbiotically with Nitrosomonas as has been suggested.

Soil amoebæ

Excystation of amoebæ. Miss Lettice Crump has studied the conditions governing the hatching of amoebæ from cysts and has found that morphologically similar species differ markedly in that one species will excyst only in the presence of bacteria of a suitable type while with the other, excystation is independent of the bacterial environment. This difference in behaviour provides a further specific factor likely to affect the relative numbers of different amoebæ in soil.

Nuclear division of classification of amoebæ. It is important to the study of the soil micropopulation that different species of amoebæ should be capable of identification. The classification and identification of amoebæ is largely based on the type of nuclear division, and there is great confusion at present largely owing to the processes of mitosis being wrongly described, often from insufficient material. Dr. B. N. Singh has developed a method for cultivating small amoebæ on glass slides coated with agar, that enables large numbers of amoebæ, in all stages of nuclear division, to be obtained readily and in a form facilitating the making of stained preparations. Twelve strains of amoebæ have been examined by this method and the types of division found are much less diverse than was formerly supposed, falling into two main categories. This discovery together with the further use of the new technique should result in a great simplification in classification and ease in species identification.

Mycorrhiza

In her earlier work Dr. Janet Mollison studied the distribution of the mycorrhizal fungus *Rhizophagus* in clover and wheat and found it to be abundant in the roots of both crops. Attempts to isolate the fungus and to grow it in a variety of artificial media have so far been unsuccessful.

When a series of dilutions of a soil suspension were applied to sterilized sand in which clover was grown the fungus was found to be present at a 1/10 dilution but not at a 1/1000 dilution. With a suitable dilution it may thus be possible to obtain otherwise comparable cultures with and without the fungus by which its effect on the plant can be assessed.

STUDIES ON NODULE BACTERIA (RHIZOBIUM) AND LEGUME CROPS

Geographical distribution of strains of clover Rhizobium

In continuation of the survey of the distribution of strains of clover Rhizobium, effective and ineffective in fixing nitrogen, a considerable amount of strains isolated from clover samples collected from the North and from the South West of England were tested for effectivity by Dr. Janina Kleczkowska.

A seriological study made by Dr. Margaret Read of 100 isolates from each of 17 localities has shown that strains of clover Rhizobium tend to be highly localized in their distribution, so that no rapid spread of a new strain whether or natural origin or introduced, is likely to occur under field conditions.

Establishment of clover Rhizobium in an " inoculated " crop

The abundance in some localities of ineffective strains of clover Rhizobium, suggests the use of seed inoculation to replace these ineffective strains by an effective strain in the soil. Any attempt to

introduce Rhizobium into the soil by inoculation will meet with competition for nodule formation from the native population of clover Rhizobium already present. Hence the first problem to be solved was how far a culture introduced by seed inoculation can be established in the nodules of the crop in face of this competition.

To find this out it was necessary to develop a method for recognizing a strain introduced by seed inoculation into field soil already containing many other strains of Rhizobium ,and thus for distinguishing nodules produced by the inoculum from those due to native strains. In earlier work (Kleczkowski and Thornton) it had been found that strains of clover Rhizobium fall into groups identifiable by antigen tests and that strains containing certain antigens are uncommon in British soils. If seed is inoculated with a strain containing an uncommon antigen and sown in the field, cultures isolated from the nodules later developed can be tested with suitable antisera and in this way it is possible to determine whether they are of the same strain used to inoculate the seed. By testing sufficient nodule isolates the percentage of nodules produced by the inoculum can be estimated. An extensive series of experiments were carried out in 1948 and 1949 by Dr. Margaret Read with the co-operation of the National Agricultural Advisory Service. These were conducted at 13 centres at four of which the trial was carried on for two seasons. Each experiment consisted of 16 plots, four replications sown with uninoculated seed and four with seed treated with each of three strains of nodule bacteria selected for ease of seological identification. Cultures were isolated from 20-25 nodules from each plot and tested with suitable antisera. From those tests the percentage of nodules due to the inocula were estimated. Great assistance was provided by bacteriologists of the National Agricultural Advisory Service not only in the field trials themselves but also in certain experiments in isolating cultures from the nodules. Without their generous help so extensive a series of trials involving the isolation and serological testing of 6,000 cultures could not have been carried out. The results of these trials showed that it is possible to establish a culture of Rhizobium in the crop, in competition with the native bacteria, but that different strains of Rhizobium differ greatly in their ability to become established in the field. The experiments thus point to a new principle applicable to seed inoculation practice, namely that, in the selection of a strain for seed inoculation, not only effectivity in fixing nitrogen, but also ability to compete with native strains in the soil has to be considered.

Legume inoculation

A number of inoculation trials with clover and beans have been and are being carried out in various districts by the National Agricultural Advisory Service using cultures supplied by us.

Local adaptation between clover and Rhizobium

Experiments have been made by Dr. P. S. Nutman and Dr. Margaret Read to see whether, on farms where local strains of red clover, have been developed, the clover and the indigenous nodule bacteria have become mutually adapted to give enhanced nitrogen fixation. Material was obtained from seven farms in Sweden and in experiments carried out in 1948 and 1949, bacteria obtained from each farm were tested for effectivity on the local clover strain

from the same farm and from each of the other six farms. In both experiments a small but significant effect was found, bacterial strains tending to be more effective on their own local clover strain than on the others.

Appearance of ineffective mutants of clover Rhizobium in soil

It was found by Dr. P. S. Nutman in previous work that if a pure culture of the highly effective strain " A " was kept in sterilized sandy soil from Woburn for six months, a considerable percentage of ineffective mutants appeared. This raised the practically important question whether this phenomenon was of wide occurrence in different soils or with many effective strains of Rhizobium.

To test the first point, Strain " A " was stored in sterilized samples of a range of different soils for half a year, after which the soil cultures were plated, random colonies " picked" and the resulting cultures tested for effectivity on clover.

We have again receiued much help from bacteriologists of the National Agricultural Advisory Service in setting up soil cultures and in the subsequent plating and isolations from colonies. The work showed that ineffective mutants tended to appear in acid soils and that their appearance could usually be prevented by the addition of $CaCO_3$. But in some cases mutants did appear in neutral and limed soils, so that other factors must also contribute to the effect. To test the stability of different strains of Rhizobium on soil storage, ten effective strains were stored in Woburn soil for 2 years. At the end of this time only one of these was found to have produced ineffective mutants, but this strain produced a high percentage. Dr. Janina Kleczkowska has been in charge of this work.

The production of mutants resistant to bacteriophage

It seems possible that the effect of bacteriophage in causing the appearance of a variety of mutant forms of Rhizobium might be a factor inducing a change to ineffectivity in field soils . Dr. Janina Kleczkowska has studied 'phage resistant mutants developed in cultures exposed to 'phage action. A number of these regained susceptibility to 'phage quite soon but were more liable to develop resistant mutants on further treatment with 'phage, than was the untreated parent strain. Amongst resistant mutants new colony characters were frequent. These were usually stable in artificial culture but readily lost on plant passage. Some resistant mutants also differed from the parent strain in their effectivity in the host plant. Many of these produced from an originally effective strain were ineffective, but the reverse change was much more rare. Mutants showing a change in effectivity varied very much in stability a number were stable during laboratory culture and after plant passage, but one strain was so highly unstable that it proved impossible to separate the effective and ineffective forms both of which were found in every colony after replating and plant passage.

The mechanism of attack by bacteriophage

Rhizobium bacteriophage is exceptionally good material for studying the process of attack on the bacterium and this problem has a special interest from its analogy to the infection process in plant viruses. Drs. A. and Janina Kleczkowski have examined the question how many 'phage particles are needed to start an infection. The work is still in progress but results so far are consistent with the

view that a single 'phage particle will suffice to produce infection of a liquid culture or to initiate a plaque.

The inhibitory effect of nodule and lateral root meristem on further nodule development

Dr. P. S. Nutnam has continued his earlier work on the effect on nodulation of excising nodules and lateral roots of clover. The excision of effective nodules increases the number of nodules subsequently formed but that of ineffective nodules does not do so. The excision of the meristem tips of effective nodules or of lateral roots also increases subsequent nodule numbers. These reults suggest that a substance inhibitory to nodule formation is produced in meristems. In ineffective nodules the meristem tip is ephemeral and persists for too short a time to produce an effect.

BOTANY DEPARTMENT

By D. J. Watson

P. C. Owen was transferred from the Physics Department to the Botany Department in January.

J. H. Wilson, of the Department of Agriculture, Tasmania, joined the department in January, as a temporary worker.

Miss G. N. Thorne was appointed in October to work on nutrient uptake from solutions sprayed on leaves.

Micronutrients

The interaction of molybdenum and nitrogen supply has been studied in lettuce and red clover grown in solution culture. For the lettuce, nitrogen was supplied at three rates, in all combinations with three rates of molybdenum supply (0, 0·1 and 5 or 10 p.p.m. Mo). Samples were taken on three successive occasions for dry weight, nitrogen and molybdenum determinations. No benefit from added molybdenum was found after 3 weeks treatment ; the highest rate caused a slight reduction of dry weight and visible symptoms of toxicity in the leaves. After 5–6 weeks treatment, the dry weight of a spring variety of lettuce, Tom Thumb, increased with increase in molybdenum supply at the two higher rates of N supply, but not at the lowest rate, and the depression of dry weight by the highest rate of molybdenum supply had disappeared. The positive interaction between Mo and N persisted in the later stages and became greater. In a winter variety of lettuce, Cheshunt Early Giant, addition of molybdenum gave no increase in dry weight at any stage; the highest rate of Mo supply, 10 p.p.m., caused a reduction of dry weight especially at the higher levels of N supply.

The total N content percent of dry matter was reduced by addition of Mo. In the plants without Mo there was some evidence of nitrate accumulation, though NO_3-N never accounted for more than about 10 per cent. of total N. The results, therefore, do not wholly support the conclusion of Mulder and others that Mo-deficiency inhibits nitrate reduction.

For the experiments on clover, three rates of nitrogen supply in combination with two rates of molybdenum (0 and 0·2 p.p.m. Mo) were used, in two different types of culture solution. In one experiment the plants were inoculated with *Rhizobium* and in another they were uninoculated. The nitrogen content of the culture solution used for the inoculated plants was reduced as growth proceeded, and in the later stages the plants were wholly dependent for their nitrogen supply on fixation by *Rhizobium*. The uninoculated plants grown without added Mo showed visual symptoms of Mo deficiency in the leaves, especially when the N supply was low, but at harvest after about 6 months growth, there was no detectable effect of Mo supply on dry weight or nitrogen content. The dry weight of the inoculated plants, harvested three months later, was increased by addition of Mo, and the number of nodules was depressed. This effect of Mo supply on nodule formation confirmed the results of previous experiments.

Nutrient Uptake by Excised Root Systems

The object of this work is to establish quantitative relationships between the rate of uptake of nutrient ions by excised roots and the concentration of these ions in the roots and in the external solution. Barley and pea plants were grown for 6–7 weeks in culture solutions, with varied supply of nitrate, phosphate and potassium. The carbohydrate content of the roots was varied by shading some of the plants for several days before the roots were taken for experiment. The root systems were cut off and held at constant temperature in a flowing aerated nutrient solution of constant composition. Samples taken at the beginning and on succesive occasions throughout a 24 hour period, were analysed for N, P, K and carbohydrates. The rates of respiration of the roots was measured throughout the period. A series of six experiments of this type has been carried out.

The analyses are not yet completed, but there is evidence that the rates of uptake of nitrate, phosphate and potassium were all dependent on the carbohydrate content, as well as the nutrient content, of the roots. Roots from plants grown with similar nutrient supply at different times of the year varied in their capacity for ion absorption ; this was probably the result of seasonal variation in carbohydrate content. Simultaneous uptake of one ion and loss of another was observed. The losses of nutrients from excised roots took place into solutions of higher concentration than those in which the intact plants were grown ; uptake was found only when the concentration of the ion in question in the solution used for growing the plants was much below that in the solution in which the excised roots were held.

The adsorption of nitrate by low-N roots was accompanied by a rise in the rate of respiration. Absorption of phosphate by low-P roots or of potassium by low-K roots did not increase the respiration rate. Low-P and low-K roots behaved like roots with a high content of all three nutrients in showing a decline of respiration rate throughout the experimental period, possibly due to falling sugar content. The rise in respiration rate associated with nitrate absorption is thought to be a different phenomenon from the " salt respiration " observed when plant tissues are transferred from water to a salt solution. It may be a metabolic effect, associated with rapid conversion of nitrate into organic nitrogen compounds.

Similar experiments were made with barley and pea roots dug from small field plots. The dry season made it difficult to remove the root systems from the soil without serious damage and loss of the finer branches, but in more favourable weather conditions it should be possible to obtain satisfactory field material for nutrient absorption studies.

Uptake of Sugar and Mineral Nutrients by Leaves

An investigation has been started on the effect of spraying plants with solutions of sugar or mineral nutrients. American workers have reported that when tomato plants growing at high temperatures and in low light intensities (*i.e.* the conditions in a heated glasshouse in winter) were sprayed with sucrose solution, the rate of stem elongation and the dry weight of the plant was increased. This result was confirmed, but the effects on growth were not such as would be expected merely from an increased carbo-

hydrate supply. For example, the increase in dry weight was restricted to the leaves, the part of the plant that would be least expected to suffer from carbohydrate deficiency, the dry weight of the stem was not affected although its length was increased, and the dry weight of roots was reduced. Further work on this is now in progress.

Work on the uptake of mineral nutrients by plants from solutions sprayed on the leaves was not begun until October. Its immediate object is to test a report that small amounts of potassium nitrate applied in overhead irrigation water to horticultural crops have a marked beneficial effect on growth and yield. Preliminary experiments were made to find out what concentration of nutrient salts can be used without scorching the leaves, and to determine whether appreciable amounts of nutrients can be absorbed from spray deposited on the leaves. In an experiment on young sugar beet plants, the amounts of N, P and K present in the leaves of plants sprayed daily for 6 weeks with a complete nutrient solution, was 15–40 per cent. higher than in the leaves of control plants sprayed with water. Experiments are now in progress comparing rates of uptake through the roots and through the leaves in different species. The rates of uptake of nitrogen from solutions containing equivalent concentrations of ammonium or nitrate are also being compared. Experiments to study the effects on growth of nutrients supplied through the leaves will be started in the spring when growing conditions are more favourable.

Water Relations of Germination

In collaboration with the Physcis Department, a study is being made of the dependence of germination of wheat seeds on moisture potential. The seeds are held close to the surface of a salt solution of accurately known vapour pressure, in a system kept at constant temperature ($\pm$ about 0·001°C), so that water is supplied to the seed through the vapour phase at a known moisture potential.

The first experiments, continued for 4–5 days, indicated that there was a sharply defined critical moisture potential below which seeds were unable to absorb enough water to germinate. Further work showed that the rate of germination was reduced by reducing moisture potential ; for example, at 20°C in an atmosphere saturated with water vapour, which we take as zero potential, wheat germinates in about 3 days, while at a moisture potential of –250 metres of water, it takes about 10 days. Seeds have been kept for 20 days at lower moisture potentials, and some have germinated in this time against a potential of –300 metres of water, *i.e.* a pF of nearly 4·5, considerably above the permanent wilting point (pF 4·2, equivalent to –150 metres of water). If there is a critical moisture potential below which germination cannot take place, it must be much lower than the first experiments suggested.

In the more prolonged experiments it has been found difficult to prevent fungal infection. Several methods of sterilizing the seeds have been tried, but none has been completely successful.

Biology of Wild Oats (*Avena fatua* and *A. ludoviciana*)

Work on wild oats was concerned with their growth and nutrition

in comparison with cereal crops, and various aspects of the dormancy of the seeds.

Susceptibility to manganese deficiency

The susceptibility of wild oats to " grey speck " disease, caused by deficiency of manganese, was compared with that of two varieties of cultivated oat,- Scotch Potato, which is said to be relatively resistant, and Star. Plants were grown in pot culture in a manganese-deficient Fen soil, without added Mn, and with Mn added at three rates, the highest rate being fixed at a level estimated as adequate to correct the deficiency. *A. ludoviciana* showed the greatest response to Mn supply in total dry weight, shoot number and shoot height, and was the first to show chlorosis at the lower rates of Mn supply. The leaf symptoms of Mn deficiency in this species were different from the characteristic grey-speck lesions found in the cultivated oats and *A. fatua* ; they consisted of interveinal chlorotic stripes which later became necrotic. The effect of Mn supply on dry weight at harvest did not differ greatly in Star and Scotch Potato, but Mn deficiency caused more severe leaf symptoms and greater delay in ear production in Star. *A. fatua* was the least affected by varying Mn supply. Mn-deficient wild oats showed a smaller per cent. reduction of seed number, but a greater per cent reduction in weight per seed than cultivated oats.

Analysis of growth and response to nitrogen of wild and cultivated oats

One way in which weeds reduce crop yield is by competition with the crop for the supply of nutrients, especially nitrogen, in the soil. Pot experiments are in progress to test whether wild oats differ from cereal crops in their ability to take up nitrogen. An experiment comparing the two species of wild oat with barley at three levels of nitrogen supply has been completed, and a second one, comparing wild oats with cultivated winter oats and winter wheat was set up in November. Samples were taken at intervals for determination of nitrogen content, and the usual measurements required for growth analysis (dry matter, leaf area, shoot counts etc.) were made to see whether there are any attributes of growth other than nitrogen uptake that may give wild oats a competitive advantage.

Dormancy of the seeds

In a field experiment on potatoes on Rothamsted Farm, wild oat seedlings were found only in the ridges where dung was applied. This observation suggested either that the dung had contained viable wild oat seeds, or that it had broken the dormancy of seeds already present in the soil. To test these possibilities, samples of dung, unfortunately not from the same bulk as was used for the potato experiment, were brought to the laboratory, spread in pans with and without the admixture of sand, and kept watered to induce non-dormant viable seeds to germinate. Seeds of *A. fatua* or *A. ludoviciana* were added to similar pans of dung and equal numbers of seeds were sown in wild-oat-free soil. The added seeds have begun to germinate both in dung and soil, but so far no seedlings have appeared from the dung without added seeds.

Dormancy in *A. fatua* is apparently due to impermeability of the seed-coat to oxygen, for germination can be induced at any time by pricking the seed with a needle. Seeds of *A. ludoviciana*, however, cannot consistently be made to germinate by pricking, and evidently

this species exhibits dormancy due to factors in the embryo or endosperm, as well as dormancy due to impermeability of the seed-coat. Some time has been spent in developing a technique for growing excised embryos of wild oats on nutrient agar, with the intention of using it to study the causes of dormancy of the embryo.

An anatomical and microchemical examination showed that the seed-coats of *A. fatua* and *A. ludoviciana* are very similar in structure.

Physiological Effects of Virus Infection

Seed-certification schemes for the control of virus diseases in potatoes depend on the recognition of infected plants in field crops by inspection. It is, therefore, important to know whether the presence, or the intensity, of visible leaf symptoms depends on the conditions of growth. A pot experiment was set up to determine the effect of varying nutrition and light intensity on the symptoms of leaf-roll infection. Small sets cut from healthy or infected tubers of Craig's Defiance, were grown with varied supply of N, P, and K with full daylight or under muslin shades which reduced the light intensity to about half that of full daylight. Some of the plants grown from healthy tubers were infected by means of aphids soon after the shoot appeared. It was found that high N supply and shading both tended to mask the leaf-rolling and yellowing symptoms. The same experiment provided material for a growth analysis study, the object of which was to determine the changes in growth caused by infection that lead to a reduction of yield, and to study the interaction of infection, nutrient supply and shading. Samples were taken at fortnightly intervals during the growth period for the measurement of dry matter in the different parts of the plant, and the total leaf area. Other attributes of growth including the number of leaves, lateral shoots and tubers and shoot height were also measured, and samples were kept for determination of nutrient content. The data obtained are now being analysed.

In collaboration with the Plant Pathology Department work on the effect of infection with yellow virus on the carbohydrate metabolism of sugar beet has been continued. This confirmed previous experiments in showing that the accumulation of starch and sugars in the leaves of infected plants is not attributable to an inhibition of translocation, as earlier workers thought.

Field Work

Samples of hay for botanical analysis were taken from twenty plots of the Park Grass experiment, selected because no analyses of the herbage on them had been made in recent years. When these analyses are completed, information on the present composition of the flora of all the plots will be brought up to date. Dr. Brenchley has continued to work on the revision of her book " The Manuring of Grassland for Hay," which describes the changes induced in the flora of these plots by long continued difference in manuring.

The usual routine observations were made on the weed flora of Broadbalk and Hoos fields.

A growth analysis study to compare the effects of nitrogenous fertilizer on spring sown wheat, barley and oats and to analyse the responses in yield, was carried out on small field plots. Samples were taken at fortnightly intervals from the end of April to early

August for the determination of dry weight, leaf area and nitrogen content. An attempt was made to estimate the dry matter contributed by photosynthesis in the inflorescence of each species, by measuring the dry matter increment over short periods of plants from which the ears were removed, in comparison with intact plants. Nitrogen determinations on the samples, and the statistical analysis of the data, have not yet been completed.

STATISTICS DEPARTMENT

By F. Yates

During 1949 the work of the department has developed along the lines which have been outlined in previous reports. Considerable progress has been made in our relations with the National Agricultural Advisory Service. Work on surveys of the operational research type has been intensified, and the year has seen the installation of Hollerith equipment.

The outstanding new survey carried out during the year is the Survey of Marginal Land. This was undertaken at the request of the Agricultural Research Council. The object of the survey was to investigate how far marginal land of the type not included in the Hill Farming Act, and not producing cash crops such as dairy products, was likely to repay any scheme of rehabilitation. The survey is being carried out in three regions ; that for East Wales and the Welsh Borders has already been completed and a preliminary report prepared.

The Survey of Maincrop Potatoes was continued, and the pilot survey of Methods of Milk Production was also continued, though a report has not yet been issued. Some analytical work on the Survey of Fertilizer Practice was carried out. A Survey of Opencast Coal Sites is being planned.

Design and Analysis of Experiments

The design and analysis of experiments for Rothamsted and other research stations has continued on the usual lines. In addition to the design of field experiments a number of laboratory experiments have been designed for other departments. Similar work has been undertaken on request for other research stations.

The grazing experiment on the residual manurial value of feeding stuffs, which was being conducted at Rothamsted on behalf of the Royal Agricultural Society of England, came to an end in 1948 and members of the department corroborated in a report on this survey which has now been prepared for publication in the Society's journal (56).

Co-operation with the National Agricultural Advisory Service in the field of experimental design and analysis has made very satisfactory progress. We are now consulted by all the provinces, and Dr. Boyd or some other member of the department usually attends meetings of Provincial Experiments Committees in most provinces. Although this involves the department in a good deal of work it should produce valuable results both in raising the standard of design of individual experiments, and what is even more important, in providing a basis for the joint planning and co-ordination of experimental investigations. After a slow start there are now also welcome signs that the machinery set up by the Ministry of Agriculture to assist in this planning and co-ordination is beginning to function. It is hoped that during the coming year this headquarters organization will have an increasing influence both on the planning of co-operative experiments carried out by the National Agricultural Advisory Service on commercial farms and also on the planning of experiments on the Ministry's experimental husbandry farms.

Various problems in the theory of the design of experiments have been investigated in the course of the year. Mr. F. J. Dudley, of the National Institute of Poultry Husbandry, and Mr. D. R. Read published a paper on the design of experiments in egg production of poultry (58). Dr. P. M. Grundy prepared a paper on the estimation of error in rectangular lattices (59), and Mr. M. J. R. Healy and Dr. Grundy have prepared a paper on the use of the principle of restricted randomization in quasi-Latin squares (60). The general basis of this principle, which is of fairly wide application, was discussed by Dr. Yates in two lectures on the logical basis of experimental design, and recent developments in the subject, given in Paris to the Institut Henri Poincaré in December, 1949 (69), (70). Dr. Yates contributed a paper on the place of experimental investigations in the planning of resource utilization to the Plenary Session of the United Nations Scientific Conference on the Conservation and Utilization of Resources (66), though he was unable to attend the Conference. He also gave a paper on experimental techniques which are of value in plant improvement to the meeting of the Biometric Society held in Geneva (68). Mr. Healy also attended this meeting. Mr. H. D. Patterson carried out some research into change-over trials such as are suitable for animal feeding trials, and has prepared a paper on this subject (64). He also prepared a thesis on which he was awarded the degree of M.Sc. at the University of Leeds (63). Mrs. P. M. Cox (Clarke) has written up an account of the analysis of $p \times q$ lattice designs (57).

Sampling Methods

Various members of the department have continued work in this field. Mr. D. R. Read published a paper on the accuracy of sampling methods for the estimation of egg production and mean egg weight (65). Dr. Yates attended the third meeting of the United Nations Sub-Committee on Statistical Sampling which was held in Geneva, and he and Mr. Healy attended the meeting of the International Statistical Institute held in Berne. At the latter Dr. Yates gave a paper on the use of sampling survey methods and operational research techniques in agriculture (67). Dr. Yates gave two papers on recent developments in sampling methods to the Institut de Statistique in Paris (71), (72). He also gave four lectures on sampling methods to the school (Centre Europeen) set up by the Food and Agriculture Organization of the United Nations for the training of official statisticians in the collection of population and agricultural statistics.

The book on sampling methods in censuses and surveys referred to in the 1948 report was published in May, 1949. From correspondence which has been received from Colonial workers and others and from personal discussions, it is clear that the book is fulfilling its purpose of providing a standard textbook whereby workers without extensive statistical training who are concerned with the conduct of sampling surveys can undertake them with confidence. A number of plans for sample censuses and surveys based on the methods explained in the book have been submitted to us for our opinion, and it is gratifying to find that the proposals have almost invariably been sound.

Survey of Marginal Land

A survey of marginal land in England and Wales is being undertaken at the request of the Agricultural Research Council, with the object of investigating what improvement in production is possible from this type of land, and what expenditure would be necessary to attain it. The survey has been organized and carried out under the direction of Professor W. E. Ellison of the University College of Wales, Aberystwyth, and Dr. Boyd. Three areas have been selected for field survey: East Wales and the Welsh Border, Northern England, and South-Western England. The Welsh survey was begun at the end of September and a preliminary report was completed before the end of the year. Field work is in progress in the Northern and South-Western counties.

The boundaries of the surveyed regions have been chosen so as to include those areas in which the farms were not, in the main, producing cash crops, fat stock or milk, and which were not eligible for full benefits under the Hill Farming Act (1946).

The sampling procedure for the Welsh region was as follows. Within the region a stratified random sample of eight parishes or part parishes was selected for survey. Within these parishes or part parishes either all, or a random half of the farms of over 25 acres crops and grass were included in the survey, with the exception of farms that were receiving Hill-Sheep subsidy at the full rate, or of which more than 30 per cent. of the acreage consisted of land of good natural fertility. One hundred farms in all were included in the sample. Each of these was visited by a surveyor who recorded sales and purchases of crops and stock and made a field-by-field survey of the farm. This field survey involved a record, for the years 1948 and 1949, of the cropping, the yields or stock-carrying capacity (estimated or actual), and the manuring and liming. The surveyor also recorded what improvements he considered to be required in respect of cultivations, manuring, draining and fencing; their cost; and what yield or stock-carrying capacity could be expected from the field over a period of six years following the improvement. The surveyor was instructed to consider what improvements were desirable from the point of view of the farm as a unit, so that, for example, one field might be scheduled for arable production and another for direct reseeding, in the light of the probable needs of the farm as a whole and aiming as far as possible at self-sufficiency throughout the year. The extent to which improvements to buildings, roads and services were required was recorded by a special fieldman who visited about one third of all the surveyed farms.

Survey of Maincrop Potatoes

This survey, which was organized at the request of the Agricultural Improvement Council and begun in 1948 (73), (74), has been continued on the same lines in 1949. The field work has been carried out by officers of the National Agricultural Advisory Service.

The survey is intended to furnish comprehensive and precise information on the agricultural practices followed in growing maincrop potatoes, including cultivations, manuring, varieties, source of seed, pests, diseases, etc. It is also designed so as to test the possibility of estimating the yield of the potato crop by

digging up and weighing short lengths of row as near to lifting date as conveniently possible. In 1949 weights of sample lengths of row on some of the fields were also taken in August, in order to investigate the possibility of predicting the yields from measurements of this type.

In 1948, which was a particularly good year for potatoes, the sample yields gave results decidedly above the official estimates of the Ministry of Agriculture. The results for the mean of all the surveyed counties were as follows:

		tons per acre
Gross yield of samples (1¼ in. riddle)		10·8
Less		
Ware left in ground after harvest	0·8	
Correction for change of riddle (1¼ in.—1½ in.)	0·3	
Correction for headlands, etc. included in acreage	0·4	
Total		1·5
Estimated corrected yield of ware		9·3
Ministry of Agriculture's estimate		8·1
Difference		1·2

A similar comparison should be available in the near future for 1949, but at present we are awaiting the Ministry's estimate. The mean sample yield for 1949 over all the counties surveyed was about 2 tons per acre less than 1948 (75).

The corrections given in the above table for ware left in the ground after harvest and for differences in area were estimated by sampling methods. It will be seen that the amount of ware left in the ground after harvest, 0·8 tons per acre, is very considerable. A check on the accuracy of the sampling and of these corrections was obtained by comparison with farmers' weighed yields, where the latter were available. The mean excess of the gross sample yields was found to be 1·6 tons per acre, agreeing closely with the total correction of 1·5 tons given above. The sampling standard error from all causes was approximately 40 per cent. per field. About 1,600 fields were included in the survey, but allowing for variations in weighting the "effective" number was of the order of 1,000, giving a sampling error of about ±0·12 tons per acre.

Apart from yield estimates the most striking result that emerged from the 1948 survey results was the marked association between late planting and low yields. Indeed, the time of planting was the factor amongst all those recorded which produced the largest apparent effect on yield. In those parts of the country where early planting was common (in particular the south-west and the Fens) there is a general indication that March plantings yielded at least a ton more than those in the first half of April, although the later plantings show little further loss. Data for the south-eastern and southern counties and for the West Midlands suggest that time of planting had little effect on yield up to the middle of April, but that, for seed put in after this time, delayed plantings gave a substantial loss, amounting to about three quarters of a ton per acre per week. It is, of course, too early yet to say whether this effect

is likely to occur in all seasons, but the result agrees with such few experiments as have been done on the effects of late planting. These experiments have indicated on the average a steady loss on the total yield of just over 0·5 tons for each week's delay up to the beginning of June. It is clear that further experimental work is required on this point.

The 1949 results are now under analysis, and the comparison between the results of the two seasons, which were meteorologically very different, should prove of considerable interest.

Colonial Work

The department has agreed to accommodate a statistician to be appointed by the Colonial Office. This statistician would be required to summarize the results of previous colonial experimental work, and assist in the Colonial advisory work undertaken by the department, particularly in the fields of experimental design and analysis, and sampling methods for censuses and surveys. A suitable candidate for this post was in fact found, but unfortunately through administrative delays the appointment fell through, and no other suitable candidate has yet offered himself.

We have had the usual volume of consultant work for the Colonies, in particular Mr. Church has continued his work for the West African Cacao Research Institute and has been invited to pay them a short visit. Four workers from the Colonies worked in the department for varying periods and we have had a large number of visitors from the Colonies.

Other Work

Many miscellaneous problems have been submitted to the department in the course of the year. In particular Mr. Dyke and Miss Poulton carried out an analysis of the results of a series of world-wide collaborative tests on the analysis of pyrethrum flowers (76). Mr. Dyke has continued to act as statistical adviser to the Advisory Entomologists. Mr. Healy has been giving assistance in the analysis of a series of anthropometric observations to the Department of Anatomy, Birmingham University. In addition, Mr. Healy prepared a paper on the routine computation of biological assays involving a quantitative response (61), and Mr. Jolly has evolved a method for the use of probits in combining percentage kills (62).

Hollerith Equipment

A Junior Rolling Total Tabulator was installed in June, 1949, as promised, and has been in active operation since then. It has already proved its value. As was expected, having a machine on the spot under the direct control of the research workers has resulted in a far more enterprising and flexible approach to punch-card work than was the case when all tabulations had to be carried out at a separate bureau. The choice of the Junior Tabulator has also proved a happy one, as this machine is sufficiently simple to be mastered by the research workers who require to use it in the course of their research, and at the same time is capable of a wide variety of operations, which are of use in research work. We are at the moment negotiating with the Company for some special modifications which will further increase the utility of the machine. In addition to its use in the analysis of survey work, we are exploring

the possibilities of carrying out the analyses of the more complicated experiments on this machine—particularly those which involve a number of different measurements on which analyses of co-variance as well as variance are required. This type of analysis has proved to be too heavy for routine work on desk calculating machines, and consequently has tended to be neglected.

STAFF

The following appointments were made in the course of the year: Dr. P. M. Grundy (October, 1949. Previously working at Rothamsted as a Ministry of Agriculture scholar); Mrs. M. Hale; Mr. P. R. D. Avis (December, 1949) from Nottingham University.

The following members of the department left to take up appointments: Mrs. M. Hale (October, 1949) Spectrographic Department, Magnesium Electron Ltd.; Mrs. P. M. Cox (Clarke) (December, 1949) National Institute for Research in Dairying; Miss M. A. Creasy (October, 1949) to take up a Ministry of Agriculture Scholarship at Oxford University.

Ministry of Agriculture Scholars: Dr. P. M. Grundy (to October, 1949); D. H. Rees (October, 1949) from Imperial College, London University.

Workers from other Stations: Mr. C. P. Cox (National Institute for Research in Dairying, Shinfield) was accommodated in the department until December, 1949. Mrs. C. P. Cox also worked here from her appointment in November, 1949 until the end of the year. Mr. J. A. Nelder, who was appointed in October, 1949 as statistician to the newly set-up Vegetable Research Station, is working at Rothamsted until accommodation is ready for him at this Station. Eight temporary workers from other organizations, four of them from the Colonies, worked in the department for varying periods during the year:—

Name	*Location*	*Period*
British Isles		
P. N. Harvey	Norfolk Agricultural Station, Sprowston, Norwich	March 1949—April 1949
G. Carruthers	Royal Navy (afterwards to University of Cambridge)	May 1949—September 1949
R. M. Jones	University of Cambridge	May 1949—July 1949
Miss H. Wilton	Grassland Research Station, Drayton	November 1949
Gold Coast		
J. Quartey	West African Cacao Research Institute, Tafo	April 1949—April 1950
R. Wickens	West African Cacao Research Institute, Tafo	November 1949—March 1950
Nigeria		
A. N. C. Thomas	Department of Agriculture, Nigeria	September 1949—October 1949
East Africa		
W. B. Tripe	Census Officer, Dar es Salaam, Tanganyika	October 1949—November 1949

PLANT PATHOLOGY DEPARTMENT

By F. C. Bawden

Dr. F. M. L. Sheffield who has held the post of cytologist in the department since 1929 left in October to join the staff of the East African Agricultural and Forestry Organization. Dr. F. M. Roberts was seconded in November to work for a year with the Clove Research Scheme in Zanzibar.

During the spring, the field station for research on sugar beet diseases was transferred from Hackthorn to more convenient and larger premises on an airfield at Dunholme Holt.

Dr. R. Hull attended two conferences, one in Belgium in February and the other in France in July, organized by the International Institute for Sugar Beet Research; Mr. F. C. Bawden attended the Fifth International Congress for Comparative Pathology, at Istanbul in May; Mr. H. L. Nixon attended the meeting of the Electron Microscope Society in Holland in July.

In March Mr. F. C. Bawden visited Zanzibar as a member of the mission sent by the Colonial Office to report on a proposed scheme for the control of sudden death disease of cloves.

Dr. P. H. Gregory was awarded the D.Sc. degree of London University.

Viruses and Virus Diseases

Laboratory and glasshouse work

The performance of the electron microscope was much improved by fitting new lenses and eliminating faults in the electrical system and its resolving power for favourable specimens is now about 2 mμ. It has been mainly used to study viruses but such varied subjects as insect cuticle, fungus spores and clay minerals have also been examined. Using the shadow-cast technique, the sizes and shapes of several viruses and virus strains were determined, some by the direct examination of clarified infective sap and others in purified preparations. Tobacco mosaic, potato X, potato Y, potato paracrinkle, tobacco etch, henbane mosaic, cucumber mosaic and cabbage blackring viruses all have rod-shaped particles of constant widths either about 10 mμ or about 15 mμ but variable lengths. Tomato bushy stunt, tobacco ringspot, a newly discovered virus from broad bean and the various tobacco necrosis viruses studied have spherical particles. Infective preparations of the Rothamsted culture of tobacco necrosis virus nave particles of two sizes, whereas crystalline, largely non-infective preparations contain only the smaller particles; the relationship between these two lots of particles is obscure. No specified particles were identified in the sap from plants infected with potato leaf roll, tomato spotted wilt, cauliflower mosaic, beet yellows and beet mosaic viruses, presumably because these occur too diluted or are similar in size and shape to normal host constituents. No virus particles could be detected in the contents of stomachs of infective aphids. The changes in properties of potato virus X during purification are correlated with the aggrega-

tion of separate particles into extensive rope and net-like structures (101).

A previously undescribed virus found causing much damage to a crop of broad beans in the midlands showed some unusual properties. Sap from infected plants contains large quantities of a specific antigen not present in healthy beans, giving a precipitin titre of about 1/500, approximately the same dilution end-point at which sap also ceases to cause infections when inoculated to healthy plants. Although highly resistant to heat, sap still being infective after 10 minutes at 90°C., infectivity is lost in a fortnight at room temperature. All plant viruses previously studied are precipitated by one-third saturated ammonium sulphate solution, but the bean virus is not precipitated until the salt concentration reaches three-quarters saturation. It has been isolated in the form of a ribose nucleo-protein, which has not so far been made to crystallise.

A virus that appears to be related to tobacco ringspot, not previously known to occur in the British Isles, was obtained from a mottled syringa (*Philadelphus* sp.).

The loss of precipitating power of antisera to viruses and other antigens that occur during the early stages of heat denaturation is partially reversible. When the heated sera are incubated with trypsin the complexes, which were formed by antibodies uniting with other serum proteins, are disrupted and the antibodies liberated in a form in which they again precipitate their antigens.

With the development of a suitable method for applying statistical tests for significance to counts of local lesions, the effect of dilution on the numbers of lesions produced by viruses could be tested for compatibility with contrasting hypotheses. Experimental results fitted the hypothesis that variable numbers of virus particles are needed to produce a lesion at different sites and were incompatible with the previously held idea that lesions are produced by chance encounter between single virus particles and uniformly susceptible sites (100).

Considerable work was done with potato leaf roll. Infected tubers were freed from the virus when maintained at 37·5°C. in a humid atmosphere for periods of 20 days (99). *Datura stramonium* is more readily infected than potato by aphids; symptoms develop more rapidly and are more easily identified with certainty in the current season. Using *D. stramonium* as a test plant a series of experiments was started to gain information on the factors that influence the transmission of leaf roll virus by *Myzus persicæ*. Other viruses whose transmission by aphids was studied were pea mosaic, pea enation mosaic (96), cauliflower mosaic, cabbage blackring, sugar beet yellows and sugar beet mosaic. With some of those, more infections were caused by infective aphids if their feeding on healthy plants was repeatedly interrupted than if they were allowed to feed undisturbed. In an attempt to gain information on the feeding habits and movement of aphids, experiments have been started using plants containing radio-active phosphorus.

Experiments on the effects of host-plant nutrition on the susceptibility to infection and on the multiplication of certain viruses were concluded (88, 89). Reducing light intensity, increasing humidity and the amount of water supplied to host plants before inoculation increased their susceptibility to infection with

several different viruses. Whether these effects reflect changes increasing the likelihood of injuries occurring at the time of inoculation, or changes in the constitution of cells that facilitate the establishment of virus particles, is uncertain. Such treatments appear to have little effect on the concentration of virus reached in infected plants. No evidence was obtained to support the claim of French workers that spraying infected plants with growth hormones greatly reduces virus multiplication. Sap from *Datura stramonium* plants infected with potato virus X, and from tobacco plants infected with viruses X and Y, which were severely deformed as a result of spraying with 2:4-dichlorphenoxy acetic acid or with 2-methyl-4-chlorophenoxy acetic acid, gave the same precipitin titres with virus antisera as sap from unsprayed plants; sap from sprayed and unsprayed plants also seemed equally infective and produced similar symptoms when inoculated to healthy plants.

Further work was done in attempts to find the nature of the cause of the yellowing disease that occurs in a Breeders' line of sugar beet, Family 41 (103). Seed from each of 20 single plants produced yellowed plants, but the extent and time of appearance of yellowing varied with different plants. Seed has been saved from the crosses green × green, green × yellowed and yellowed × yellowed, to see what influence the appearance of parent plants has on that of the offspring. Seed was also saved from Kleinwanzleben E plants that had been colonized with aphids from yellowed family 41 plants, to see whether the condition is transmitted through the seed of other lines of beet. Only 3 of 50 Klein E plants colonized developed symptoms, suggesting a much smaller rate of transmission than is usual with beet yellows virus.

Beta patellaris, *B. maritima*, a cross between the two, and two samples of polyploid beet, selected at Cambridge as possibly resistant or tolerant to yellows, were all susceptible and were infected by aphids as readily as commercial beet. There was some evidence that the type of symptoms, particularly whether or not there was etching of the veins or leaf necrosis, depended on the variety.

Evidence was also found for the occurrence of beet mosaic virus in strains of different virulence, one of which seems to cause the "silver-leaf" disease prevalent in some varieties of red beet. The same isolates of mosaic virus, however, may cause different symptoms in different varieties of red beet.

Sap from beet leaves contains material that inhibits the infectivity of beet mosaic, tobacco mosaic and various other viruses. It is destroyed by heating to 80°C., is non-dialysable and is absorbed on to activated charcoal. Its nature has not been determined but it can be precipitated and concentrated by the treatments previously used to isolate a virus-inhibiting glycoprotein from *Phytolacca decandra*.

In previous reports the underground spread of potato virus X from infected to healthy plants has been described and to gain further information on the manner whereby this occurs experiments have been made on the infection of plants through their roots. Roots of tomato seedlings became infected when they were directly inoculated with tomato bushy stunt, tobacco mosaic and potato X viruses, or when these viruses were added to soil or culture solutions in which plants were growing. Sometimes the viruses remained

localised and multiplied only around their initial entry points, sometimes they invaded the whole root system but did not enter the aerial parts, and sometimes they produced a full systemic invasion of roots and shoots. When the roots of potato plants were inoculated with virus X, tubers set were often infected though the virus rarely spread into the haulm and caused symptoms.

FIELD WORK

There was the earliest and most severe attack of sugar beet yellows in 1949 we have yet experienced; on most plots all the plants were infected soon after singling and this unusually early and high incidence of the disease meant abandoning experiments designed to test the effect of varying plant population, and of introducing scattered sources of infection, on the incidence and spread of yellows. Beet mosaic was much less prevalent, and with this, as with yellows in previous years, reducing the density of the stand increased the percentage of plants that became infected. Contrary to general belief, uneven spacing had no effect on the incidence; the same percentage of plants became infected in plots carrying the same total of plants per unit area whether they were uniformly distributed or spaced irregularly with variable gaps.

Despite the dry summer, the irrigation of sugar beet had no effect on the aphid infestation or on the incidence of yellows and mosaic. Overhead watering did not wash the aphids off the plants and the peak aphid population was similar on irrigated and unirrigated plots. Early in the season more virus-infected plants were counted on the irrigated plots, but later there was no difference, and the effect is probably attributable to a delay in the development of symptoms in the unwatered plants.

The value of raising sugar beet stecklings in districts isolated from sources of yellows virus was again demonstrated. Four lots of stecklings from the north had less than 1 per cent. plants infected; four from Wales had 1, 1, 5 and 6 per cent. respectively, and one from Gloucestershire had 6 per cent., whereas four lots from the eastern counties all had more than 85 per cent. plants infected with yellows; the last also had considerably more plants with mosaic and downy mildew. Sowing under a cover crop of barley also reduced the incidence of yellows; seed sown under barley in April 1948 gave stecklings 11 per cent. of which had yellows compared with 87 per cent. and 100 per cent. for a July and September sowing without cover.

Spraying with some of the new systemic insecticides gave useful results in reducing the prevalence of yellows in the seed bed. Stecklings were sprayed from one to three times in the autumn of 1948; in June 1949 85 per cent. of the unsprayed plants were infected whereas those sprayed three times with E 605 had 10 per cent., with Pestox III 23 per cent. and HETP 41 per cent.; octachlor and nicotine were much less beneficial. With all the insecticides, the first spraying was least beneficial and the last the most. Experiments with insecticides on the root crop in 1949, like those on plant population, gave no useful results as yellows was too prevalent on the plots before the treatments had time to operate.

In an attempt to find lines of beet resistant or tolerant to yellows, more than 700 different lots were grown on a plot surrounded

by infected seed plants. The lines which had the largest proportion of healthy looking plants and showed least yellowing have been selected for further study.

In potatoes, as in sugar beet, there was an unusually early and extensive spread of viruses. The populations of *Myzus persicæ* on the early spring hosts were higher than for many years and large numbers migrated to potatoes in late May. There were also many winged *Macrosiphum euphorbiæ*, *Aphis rhamni* and *A. fabæ*, but the large numbers of predators and parasites that soon developed prevented the production of a large infestation of apterous aphids. Overhead irrigation greatly increased plant size and yield of tubers, but did not affect aphid populations, which were uniformly small. The aphids present were uniformly distributed per area of land and not per plant, so that plants spaced three feet apart carried twice as many as those spaced 18 in. and four times as many on those spaced 9 in. DDT, E 605 and Pestox III sprayed at weekly intervals controlled aphids but their effects on the spread of viruses will not be known until 1950.

Records on the health of plants grown from tubers saved from experiments in 1948 showed that leaf roll spread as readily to potatoes surrounded by sticky barriers, which prevented the passage of wingless aphids, as to those not so protected, suggesting that spread is largely occasioned by winged forms. Virus Y also infected nearly as many protected as unprotected plants. Experiments on the effects of roguing again showed that the removal of diseased plants in mid-June was too late to prevent most of the spread of viruses, except for potato virus Y in Derbyshire. The experiment on effects of planting date and manurial treatment showed that viruses spread equally in plots planted at different dates, though the later ones had fewer aphids. Plots with phosphate had significantly more aphids, but the only effect of manuring on spread of virus diseases was, as previously found, that most plants became infected on plots that received dung.

An analysis of the results of experiments made in different parts of England and Wales between 1941 and 1947 showed that the spread of leaf roll is correlated with the number of winged *Myzus persicæ* caught on sticky traps throughout the season. Spread of virus Y is also correlated with these trap catches, but to a lesser extent (93).

Mycology

A wind tunnel designed for use in studying various problems in plant pathology such as the dispersal and deposition of fungus spores and protectant dusts, and aphid flight, was completed and put into operation. It is designed to work at wind speeds from 10 to 0·1 metres per second. So far tests have been made mainly on the deposition of Lycopodium spores on sticky cylinders of various diameters from 0·2 to 2·0 cm. At wind speeds from 1 to 10 M/s, the efficiency of the traps increases as the cylinder diameter is reduced and the wind speed is increased. This had been predicted by workers on aerodynamics, but has not previously been studied quantitatively. The large increase in efficiency at low speeds for very narrow cylinders that has been found, however, seems to be unpredicted.

Tests on the efficiency of spore traps in the open give similar results to those in the wind tunnel; they also show that there is a greater deposit of spores per unit area on vertical than on horizontal surfaces and that the traps are more efficient with the large spores of Lycopodium (30μ diam.) than with the small spores of Lycoperdon (4μ diam.).

A routine spore trap operated continuously in the open showed that there were not the heavy showers of either powdery mildew or *Alternaria* sp. that occurred in 1948.

Studies were continued on the effects of cultural treatments on wheat with and without eyespot (*Cercosporella herpotrichoides*). With plants grown in pots out of doors, eyespot reduced yield by 23 per cent. when ammonium sulphate was given and by 41 per cent. when it was not. Under glass, it reduced yield by 26 per cent. when nitrate was applied and by 90 per cent. when it was not. Applying nitrogen in March and April increased yields of both infected and uninfected wheat more than applications in May. In the field, spring spraying with sulphuric acid increased yields by 4·4 cwt. of grain per acre when applied to plots receiving ammonium sulphate compared with 1·9 cwt. with those that did not.

Depth to which the fungus penetrates leaf sheaths was used to measure the relative susceptibilities of 12 cereals to eyespot. There were slight differences between the seven wheat varieties tested, but all were more susceptible than oats, and rye was less than oats. *Triticale*, a wheat rye cross, was intermediate between the two parents. Whereas infection caused an average loss of 50 per cent. of grain yield in the wheat varieties, rye and oats suffered no loss.

A culture of *C. herpotrichoides* isolated from a crop of oats in Bedfordshire that was severely attacked, was as pathogenic for wheat as cultures derived from wheat, but it was more pathogenic for oats. *Lolium italicum* and *L. perenne* and *Dactilis glomerata* were infected with *Cercosporella herpotrichoides* isolated from wheat; the fungus was re-isolated from each of the grasses and found to be still pathogenic for wheat.

The survival of resting spores of *Plasmodiophora brassicæ* under various crops was again tested, but the previously reported effects of brassicæ in reducing survival were not again obtained. Studies on the relation between spore concentration in the soil, the number of root-hair infections per plant, and the proportion of plants that develop clubs, shows that clubbing can result from a few infected root hairs, and it seems that a club may develop from a single infection.

Some preliminary experiments on factors affecting the production of rhizomorphs by *Armillaria mellea* confirmed the part played by genetical factors but also indicated that the carbon/nitrogen ratio in the medium is important. Rhizomorphs were formed most abundantly with a moderate carbo-hydrate supply and little nitrogen.

BIOCHEMISTRY DEPARTMENT

By N. W. Pirie

Investigation of Leaf Components

Several years of work on the effect of enzymes from various sources has now been rounded off sufficiently for it to be written up. The essential features were summarised in last year's report.

By following the reduction in viscosity of a solution of a soluble cellulose derivative under standard conditions, Tracey has detected the presence of cellulase in saps from a number of plants. The enzyme is present in very small amounts in tobacco leaf sap, its concentration often being less than a one hundred thousandth that in snail digestive juice (the usual source of cellulase used in this department). In tobacco root sap the concentration may be five or ten times as great. It appears that the enzyme is relatively more abundant in young leaves than in old. By using large amounts of fresh active root sap it has been possible to show that finely dispersed cellulase is also attacked by the enzyme.

The readily sedimentable phosphorus-containing protein that is a characteristic component of the fresh sap of young tobacco leaves has now been found to contain several enzymes. These will not only act on extraneous substrates e.g. phosphate esters, but also bring about the denaturation of the protein itself and the liberation from it of nucleotide and, subsequently, the dephosphorylation of the nucleotide.

Large scale preparation of leaf protein has been started at the Grassland Improvement Station where a mill capable of handling up to 2 tons of fresh leafy material has been installed. This works satisfactorily, and we have now sufficient skill in its use to be able to grind any of the leaves grown in normal agricultural practice and to liberate about half the protein.

Investigations on tobacco necrosis virus have continued along the lines set out in last year's report and some progress has been made towards getting conditions defined, so that the results will be repeatable. Some of the important variables have been recognised, but the frequency with which unexpected activations, or inactivations, occur suggests that we have not recognised all of them.

Oxidation of Mn by Peroxidase Systems in Plant Extracts

The system consists of peroxidase, and a peroxidase substrate. Using partially purified peroxidase preparations, the effect of variation in the peroxidase, phenolic substrate and H_2O_2 concentration has been studied. The oxidation of Mn can be demonstrated at Mn concentrations likely to be present *in vivo*, and with a few μg. of peroxidase. The Mn probably reduces the oxidised peroxidase substrate, and thereby is itself oxidised. This involves the substrate in a cycle of oxidation and reduction. The catalytic activity of the substrate is demonstrated by the fact that under suitable conditions 1 μg. of p-cresol produced 605 μg. Mn_2O_3.

Preliminary evidence has been obtained that the oxidized Mn is reduced by plant metabolites. This is an agreement with the

hypothesis previously put forward that a Mn oxidation reduction cycle is responsible for the effect of Mn on plant respiration.

The oxidation of Mn *in vivo* by this system depends on the production of H_2O_2 by the plant tissues. It is known that H_2O_2 is formed in several oxidation reactions catalyzed by enzymes, e.g. xanthine oxidase and amino acid oxidase. Preliminary evidence has been obtained that H_2O_2 formed by these enzymes may be used by peroxidase systems to bring about the oxidation of Mn.

The possibility that the peroxidase system can oxidize metallic ions or complex ions other than those of Mn is being investigated.

Under certain conditions the addition of small amounts of salts of Mo, V and W have been found to accelerate the rate of oxidation of Mn by peroxidase systems. There is evidence that this is due to the enzyme catalyzed formation of peracids, e.g. the formation of permolybdate from molybdate. These experiments may throw light on the mechanism of peroxidase action and the physiological role of Mo.

The rate of oxidation of ferrocyanide by H_2O_2 is increased by peroxidase alone, but peroxidase together with suitable substrate produces a much more striking increase in the rate of oxidation. The oxidation of ferrocyanide is accompanied by consumption of H^+, and may be followed manometrically by CO_2 uptake in bicarbonate medium in an atmosphere of $N_2 + CO_2$.

Hydroquinone—and Hydrosulphite—Soluble Manganese of Organic Soils

It has been suggested that manganese deficiency occurring in soils with total manganese contents adequate for plant growth is due to the presence of the soil manganese higher oxides in unreactive forms. The highly reactive and potentially readily available fraction has been defined as the fraction dissolved by 0·2 per cent. hydroquinone in M-ammonium acetate at pH 7, and a moderately reactive fraction as that dissolved by hydrosulphite under the same conditions. Heintze and Mann have shown that manganese extracted from neutral or alkaline organic soils by M-ammonium acetate containing 0·2 per cent. hydroquinone at pH 7 may represent only a small percentage of the soil manganese higher oxides reduced by hydroquinone during the extraction. This is due to the retention by the soils of part of the divalent manganese formed by reduction. The amount of manganese retained in this way depends in general on the organic content of the soil. Results with the manganese minerals, pyrolusite, hausmannite, and manganite support the view that under certain conditions hydroquinone and hydrosulphite may be suitable reagents for differentiating between manganese higher oxides of different reactivity. But since hydrosulphite, unlike hydroquinone, partially prevents retention of divalent manganese by soils, differences between hydrosulphite and hydroquinone soluble manganese, on organic soils in particular, may be due not to the reduction of manganese higher oxides of different reactivity but to differences in the amounts of divalent manganese retained by the soils.

Resistant Components of Soil Fungi

Work started in October on the chemical nature of the mycelia of some representative and easily available fungi. This will later be extended to the examination of those that are prominent in soil to see whether it is likely that they contribute significantly to the building up of "soil organic matter."

NEMATOLOGY DEPARTMENT

By T. Goodey

General

Nowhere at the present time is it possible for the worker in applied biology to obtain instruction in the handling of plant and soil nematodes. The need for a course in nematology and nematological methods and techniques has been urgent for several years. At the request of the Plant Pests and Diseases Committee of the Association of Applied Biologists the staff of this department agreed to be responsible for conducting a course during the past summer. By permission of Sir Frank Engledow it was held at the School of Agriculture, Cambridge, from July 7-16, 1949. Mr. F. G. W. Jones, Entomologist in the School of Agriculture, made the necessary local arrangements and secured accommodation at Jesus College for the 30 students who attended. Selection of the students (20 of whom were from the National Agricultural Advisory Service) was carried out by the staff of the Ministry of Agriculture Plant Pathology Laboratory, Harpenden and Mr. E. Dunn, Assistant Entomologist of that laboratory acted as secretary/treasurer. A strenuous 10 days of intensive lectures and practical work was spent by those conducting and taking the course, the first of its kind to be arranged in this country. The many letters of appreciation and thanks received from those who took the course show that it was successful.

Dr. T. Goodey paid a short visit to Holland from April 26 to May 6, 1949 and spent most of the time at Wageningen in Professor H. M. Quanjer's Laboratory for Mycology and Potato Investigations. Here Mr. J. W. Seinhorst has been working for some years on problems connected with stem eelworm disease ("stock") of rye and has devised new methods for extracting the infective larvæ of the parasite, in large numbers, from dried infested rye plants and for cleaning and concentrating them. Details of these methods have not yet been published but Mr. Seinhorst kindly supplied particulars for the construction of the apparatus and gave details of the methods he has successfully developed. Similar apparatus has now been erected in this department and is in full working order. It has provided us not only with large numbers of infective larvæ of several races of the stem eelworm from teasel, oats, red clover, narcissus, and broad beans, which will be used in due course for inoculation experiments, but also with *Aphelenchoides* species from strawberry buds, violet plants and chrysanthemum leaves. On leaving Wageningen a short stay was made at the Bulb Research Station, Lisse where a profitable opportunity was taken for discussions on nematode infestations of bulbs with Professor E. van Slogteren and Dr. M. P. de Bruyn Ouboter.

Dr. Peters attended an Arable Conference at St. Helens in January and gave a talk on potato root eelworm, illustrated by the C.O.I. documentary film.

During the year two temporary workers have spent periods in the department learning nematological methods, namely Mr. R. S. Pitcher of East Malling Research Station and Mr. Sven Bingefors of the Swedish Seeds Association, Uppsala.

On the area adjacent to the laboratory our living museum of plant parasitic species and races of eelworms is now largely established and cinder paths have been made between several small plots. The two greenhouses have been fitted with an electric heating system, concrete paths have been laid, staging erected in one of them and ventilators fixed in the side walls.

Research carried out by the members of the staff falls naturally into two main sections: (1) problems connected with plant infestations by eelworms belonging to the families Tylenchidæ and Aphelenchidæ and soil nematodes generally (Dr. T. Goodey, Dr. Mary T. Franklin and Mr. J. B. Goodey), (2) problems connected with root-infesting nematodes belonging to the family Heteroderidæ, (Dr. B. G. Peters and Mr. D. W. Fenwick).

Tylenchidæ and Aphelenchidæ

Tylenchidæ

Dr. Goodey has carried out investigations on stem eelworm (*Ditylenchus dipsaci*) attacks on the fuller's thistle or teasel (*Dipsacus fullonum* L.) with a view to determining the route taken by the parasite in reaching the flower head and thus becoming dispersed in and on the seed in a dry quiescent but viable state.

He has written a booklet entitled "Laboratory Methods for Work with Plant and Soil Nematodes" which has been published by the Ministry of Agriculture and Fisheries as Technical Bulletin No. 2.

He has also revised much of the text and prepared further illustrations for his new book, "Soil and Freshwater Nematodes" which is now passing through the press and should be issued about mid 1950.

Mr. J. B. Goodey reports that work has been continued on the plant-parasitic species of *Ditylenchus*. The host-list of the Stem eelworm, *D. dipsaci*, contains the names of some 350 plants and a beginning has now been made in trying to find out which biologic race is responsible in each particular infestation. *D. destructor* the potato tuber-rot nematode has been shown to be the cause of eelworm disease of bulbous iris, hitherto ascribed to *D. dipsaci*, and further experiments are now in progress which show that *D. destructor* attacks several other hosts as well as the few already known. Some new biological aspects of the life cycle of *D. destructor* have been discovered. A paper embodying the results of these investigations has been prepared.

Reports of attacks by *D. dipsaci* on strawberry have been numerous recently and work has been carried out on the subject. It has been shown that the nematode will transfer from strawberry to oats, but it is suspected that the problem is more complex and that races of *D. dipsaci* other than the oat race may be involved.

During work on the fine details of the anatomy of D. *destructor*, a new structure was discovered on the ventral surface of the eelworm. Its function is not known but it has been found on several other genera of the super-family Tylenchoidæ. A short paper describing its form and distribution has been written in which the term 'Hemizonid' is proposed as its name.

An interesting case of *Calceolaria integrifolia* attacked by *D. dipsaci* was received during the summer in which the eelworms were themselves parasitized by a nematode-attacking fungus. Its mode of attack and development on *D. dipsaci* has been observed and the fungus isolated in pure culture. The fungus has been identified provisionally as a species of *Acrostalagmus*, possibly an undescribed one. Work on this is being continued.

By courtesy of the Chemistry Department many specimens of Conifers, particularly Sitka spruce, have been examined for the presence of certain nematodes which have been reported attacking roots of Conifers in U.S.A. A species of *Hoplolaimus*, identified as *H. uniformis* Thorne, 1949 the first record of this eelworm in Great Britain, has been found in considerable numbers. A few specimens had their heads buried in the root tissue. The matter is being pursued further, but it is considered doubtful whether the eelworms cause any but trivial damage.

Work designed to find a fixative causing little or no shrinkage of eelworms has been continued. The result, a new formal-acetic mixture, has been incorporated into a joint paper with Dr. Mary T. Franklin in which the use of dilute Cotton Blue in Lactophenol as a medium for the rapid mounting of plant parasitic nematodes, has been described. Further work on mounting media is proceeding.

Aphelenchidæ

Dr. Mary T. Franklin reports that further investigations on the two species of *Aphelenchoides* found in strawberry plants have shown them to be *A. fragariæ* and *A. ritzema-bosi*. Reference to Ritzema-Bos's original descriptions of *A. fragariæ* (1891) and *A. olesistus* (1893) have failed to show sufficient difference between them to justify the separation of the second species, moreover the successful inoculation of a fern with *A. fragariæ* from strawberry, with the production of symptoms typical of infection with *A. olesistus*, has shown that the same nematode can parasitize both plants, therefore *A. olesistus* is regarded as a synonym of *A. fragariæ*. The other species found in strawberry resembles the chrysanthemum eelworm in morphological characters and is therefore considered to be *A. ritzema-bosi*. Cross-inoculations of these worms have been made from strawberry to chrysanthemum and *vice versa*, but they have not so far yielded results. The determination of the identity of these two species in strawberry was helped by the exchange of specimens with Dr. Merlin Allen of California.

Work has continued on the blackcurrant eelworm: blackcurrant bushes infested with *Aphelenchoides ribes* have been established on the plot and a beginning has been made in studying the biology of the parasite with a view to finding out the periods of maximum activity and of migration. It has been established that the nematodes may be found wandering on the branches in wet weather in summer and also that they will move upward against a downward trickle of water. Six varieties of blackcurrant and also one each of red currant and gooseberry have been planted next to the infested blackcurrant bushes to determine their susceptibility to infection with *A. ribes*. The past hot dry summer hindered the establishment of the bushes, but it is hoped that they will make good growth during the coming year.

Small-scale warm-water treatments having established the lethal temperatures for *A. ribes*, warm-water treatments of un-rooted blackcurrant cuttings have been started with a view to finding a suitable treatment which could be used in the starting of a clean stock. The treatments used (at the beginning of December), namely, 46°C. for 25 min., 47°C. for 20 min., 48°C. for 15 min., and 49°C. for 10 min., have caused sprouting of the buds, but it is too early yet to say whether roots will be produced normally.

Cross-inoculation experiments have shown that *A. ribes* from blackcurrant can become established on strawberry plants and *A. ritzema-bosi* from strawberries on blackcurrant seedlings with the production of lesions typical of eelworm damage. Further studies of morphology and host range are being made to determine whether *A. ribes* should be regarded as a synonym of *A. ritzema-bosi*.

Violet plants infested with what must now be called *A. fragariæ* have been established on one of the plots. It has been found that the worms may be present in damaged flower buds and that the dried seed may also be infested with eelworms which become active on soaking in water.

Cultures of species of *Aphelenchoides* on agar together with fungus have been continued. *A. fragariæ* from fern has become established and also *A. parietinus*, a species commonly found in decaying plant material, which has been thought to be parasitic in some cases.

In collaboration with J. B. Goodey a new technique for processing, staining and making permanent mounts of the smaller nematodes has been developed. By transferring nematodes from fixative to lactophenol containing cotton blue at a temperature of 65-75°C. they can be cleared, stained and mounted in lactophenol in a few minutes instead of requiring several weeks in slowly concentrating glycerine. The new method is particularly useful with *Aphelenchoides* which are very easily distorted when processed by the older method.

HETERODERIDÆ

Dr. B. G. Peters reports as follows: The distribution of potato root eelworm in England suggests that peaty soils, sands, and silts are favourable and heavy clay soils unfavourable to the parasite. An investigation of these edaphic factors has been started by adding a light infestation of the eelworm to an unpromising subsoil clay, factorially modified by the addition of sand, peat, compost and mixed artificials, in which potatoes were grown in 32 large glazed pots. In the first year plant responses were not significant in terms of height of haulms at 45 days (beyond a suggestive 2·8 cm. increase from compost), or of number of tubers harvested; but weight of tubers showed a significant response to compost, peat, and fertilizers in that order, with no evident interaction effects. Counts of eelworm cysts and larvæ are not yet completed. The experiment will be continued.

Nematocidal investigations have continued on a laboratory scale and also in pots of soil grown outdoors. In the outdoor experiment 40 8-litre glazed pots, filled with soil naturally infected with *H. rostochiensis*, were injected in pairs at rates of 0, 1, 4 and 16 ml. per pot of the following: (1 & 2) two chlorphenol products, (3)

ethylene dibromide 5 per cent. v/v. in solvent naphtha, (4 & 5) D-D mixture. Apart from one set of 8 D-D pots (required for other purposes), a potato was grown in each pot. The chlorphenol materials at the rates used gave rise to no plant responses of any kind. Both ethylene dibromide and D-D at the highest rate caused a marked reduction in the height of haulms after 21 days and the yield of tubers was significantly higher at 1 and 4 ml. than at 0 and 16 ml.

A start has been made on determining the rate and direction of migration of potato-root eelworm larvæ through soil, both vertically and horizontally. To measure vertical migration, potatoes were grown in wooden boxes made by superimposing six 2-inch-high sections, 6 in. square in plan. Eelworm cysts were added at the top of some boxes and at the bottom of others. Leaching effects were controlled by watering some from below and others from above. The soil from each 2-in. section was separately collected and awaits eelworm counts.

The use of vinegar eelworm as a test animal in the preliminary selection of possible nematocides has been investigated in some detail. These eelworms are readily cultured in vinegar, neat or diluted with water, or in solutions of sucrose or ethyl alcohol or both, at temperatures up to 37°C. Living worms show a marked negative geotaxis which is made use of in concentrating them from a culture into a clean medium.

With time and temperature fixed, they are exposed to different concentrations of a nematocide in aqueous solution or emulsion. They are counted by sampling in a 1-ml. counting chamber on the haemacytometer principle. After exposure the number dead is also estimated by sampling, but many nematocides cause lysis of the worms to an extent depending on the concentration. At low kills it is impracticable to count living worms and accordingly, after estimating dead worms, sufficient iodine is added to kill the living and a further estimate is made of the total. The difference between "dead" and "total" estimates the living, and the difference between "living" and "exposed" estimates the kill. At high kills the living worms are sluggish and can be counted.

In spite of the superimposed sampling errors involved in a single estimation it is possible to secure reproducible results giving a tolerable rectilinear relation between probit and log concentration. Thus, a sample of D-D mixture emulsified with Triton N.100 has given at 32°C. a 20-hour $L.D._{50}$ of about 24 p.p.m. by volume.

This technique has been applied in an investigation, suggested by Dr. Thornton, of the nematocidal power of D-D repeatedly injected into soil at fortnightly intervals. The soil was subsequently leached with water, to which leachings vinegar eelworms were exposed. Preliminary trials indicate that, instead of a progressive accumulation of toxic material in the soil, leachings from successive injections give progressively lower kills.

Continuing the joint experiment (with the West Norfolk Farmers' Co-operative and Shell) on the effects of annual injections of D-D on a field scale, at Moulton and Prickwillow, the second-year yields of potatoes reveal the following results. At Moulton there was no significant difference between plots injected in 1947 only and

uninjected controls, but plots injected in 1948 gave a higher yield. At Prickwillow, on the other hand, there was no difference between 1948-injected plots and the controls, whereas 1947-injected plots gave a significantly lower yield. At both sites the response to D-D this year was very much less than it was last year.

Regarding other species of *Heterodera*, soil samples taken in the autumn of 1948 from all the Barnfield plots have been processed, but the counts of *H. schachtii* cysts per g. and of eggs and larvæ per g. of soil have not yet been analysed.

Mr. D. W. Fenwick reports that six principal lines of research on *Heterodera rostochiensis* have been followed during the last year.

Viability determinations

The investigations into the hypochlorite technique mentioned in the previous year's report are almost complete. The method of arriving at a reliable total count of eggs plus larvæ per cyst has been written and accepted for publication. A further refinement resulting in a saving of at least 60 per cent. in time has been introduced by Miss E. Reid and is published as an appendix to the paper.

Larval emergence

The problem of larval emergence has received considerable attention and has been investigated from the point of view of "in vitro" laboratory experiments as well as in pots of soil. A preliminary stage to "in vitro" experiments has been the investigation of variability and this forms the subject matter of a paper at present in the press. As a result of this work it is now possible to set up experiments and obtain results of a predictable accuracy and thus ensure that effects of any given magnitude can be detected with a reasonable degree of certainty.

Investigations into the form of the hatching curve are now complete and have been recorded and are accepted for publication. The sigmoid nature of the curve has been established as a sufficiently close approximation for probit analysis to be practicable. Using this, it is possible to define any hatching curve by means of three constants (1) the total number of larvæ liberated, (2) the time at which 50 per cent. of the larvæ have emerged, corresponding to a probit value of 5, (3) the standard deviation of the hatching time, corresponding to the slope of the probit line.

Experiments have been conducted with anhydrotetronic acid, which is very active in inducing larval emergence. Its effect under different conditions is being investigated with the object of determining an optimum. One complication regarding its use is that two different samples of the chemical appear to have behaved differently. The first manifested its maximum activity at 1:2000, at which it was only slightly less active than was the root diffusate. The second sample, however, appeared to be most active at 1:1000 and its maximum activity appeared to be considerably less than that of the previous sample. The first sample in solution in distilled water gave a pH of between 5 and 6 but the second in solution gave a pH of between 2 and 3, and this discrepancy is now being investigated. Great importance is attached to experiments on this chemical since its action appears to be very similar to that of root diffusate,

and it is hoped to utilize it finally as a standard against which samples of diffusate can be tested.

A considerable amount of preliminary work has been carried out on the problem of larval emergence in soil as well as on the degree of persistence of root diffusate in soil. In the former case a large scale preliminary experiment has been conducted in which potato plants of three varieties were grown in a 3:1 mixture of loam and sand. Leachings from these plants were drained into three types of naturally infested soil. It was found that leachings from soil alone resulted in a 50 per cent. hatch, whilst in the case of potato leachings about 86 per cent. of the larvæ emerged. Significant differences were found to exist between soils and there was evidence of differences in degree of emergence due to leachings from different host varieties. A paper has been written on this subject and has been accepted for publication. Further experiments are in progress on the persistence of root diffusates in soil.

Population fluctuations

Parallel with experiments on larval emergence a series of experiments has been conducted to investigate fluctuations in eelworm populations during the growing season. This has been approached from two angles (1) estimation of the gross changes occurring in the whole population and (2) the rate of penetration of larvæ into new hosts.

Factors influencing larval penetration

Repeated failure to obtain infections by inoculating larvæ into clean soil containing growing potato plants resulted in making a simple experiment on the effect of different conditions on the penetration of eelworm larvæ. It was found impossible to infect plants grown under greenhouse conditions and very few cysts developed on plants grown in full sun. The highest yield of cysts was obtained from plants grown in the shade and in gravel plunges. It is believed that this result is a temperature effect, the high temperatures attained in a greenhouse being detrimental to larval penetration. Further experiments on this are contemplated in the coming season.

D-D experiments

A number of small scale experiments have been carried out on the soil fumigant D-D. The results of experiments mentioned in last year's report on the apparent unreliability of the "buried bag" technique are now complete and a letter has been written to "Nature" on this matter.

"In vitro" experiments are in progress on the nematocidal effects of D-D under different physical and chemical conditions. The effect of humidity has been investigated; and it has been found that a high humidity is essential for maximum effect.

An experiment has been carried out on the nematocidal properties of four different samples of D-D. It has been found that the samples exhibited significant differences in nematocidal properties, these differences being most marked at high mortalities. It was found that 7 times as much of one sample as of another was needed to secure a 99 per cent. kill. The results of these experiments have been recorded and accepted for publication.

Fungi infecting Heterodera *cysts*

In conjunction with Mr. C. L. Duddington of Regent Street Polytechnic, an investigation is in progress on the identity and biology of fungi found infecting *Heterodera* cysts. A number of these have been identified and there can be little doubt that at least one is present as a natural infection within the cyst. Attempts are being made to find a fungistatic agent which will prevent the development of these fungi in hatching experiments. The possibility of using these fungi on a field scale as a method of biological control is being considered.

In conjunction with Dr. Mary T. Franklin the analysis of data on the larval lengths of different species of *Heterodera* is complete and has been accepted for publication.

Co-operation with Dr. H. C. Gough of Cambridge in long term investigations on eelworm population changes during crop rotations on different soils is also continuing.

ENTOMOLOGY DEPARTMENT

By C. B. Williams

Staff

During the period Mr. R. A. French joined the staff as an Assistant Experimental Officer, Dr. G. O. Evans has worked on a grant from the Forestry Commission, and Mr. J. E. Satchell has worked since August, 1949 on an Agricultural Research Council Scholarship. Mr. C. J. Banks also came to work early in 1949 on a research grant for the Agricultural Research Council to study Biological Control, but unfortunately was taken ill shortly afterwards and was not able to resume his investigations during the year.

Insect Ecology

Dr. Williams has continued his work on the relation of insect abundance to weather conditions. Trapping, on which this work is based, was continued throughout the year in three traps—bringing the post-war period of trapping to 3½ years. Trapping will be stopped early in 1950 when the fourth post-war year is completed. All the work of the year supports the previously published results on the relation of activity to weather conditions. Insects are, in general, more abundant after wet weather in the summer and after warm weather in the winter.

Work was continued on the relative abundance of different species of insects in random samples of wild populations, with particular reference to the interpretation of the frequency distribution either as a logarithmic series or a log-normal distribution. A big experiment carried out in July 1949 unfortunately gave inconclusive results.

Many of the results of these investigations have been found to be applicable to botanical problems and a paper is in the press discussing the relation of the logarithmic series to quadrat sampling of plant.

Work on migration of insects continues chiefly through the co-operation of naturalists in different parts of the world. There was no outstanding immigration of pests into Britain during 1949.

Gall Midges

Dr. Barnes reports that the expected fall in numbers of the wheat blossom midges in 1949 took place, there being 7,698 larvæ of the species in the 500 ear samples as compared with 15,417 in 1948. The percentage grain attack fell from 14·7 to 7·7. The year 1949 was not such a good one for emergence as was 1948 and the weather at the time of oviposition was not particularly favourable. The descent of the larvæ from the ears took place about 17th July which was about the same as in 1946 and 1947, but earlier than in 1948, and later than in 1945, a particularly early year.

His investigation of *Contarinia nasturtii* was particularly successful. He was able to rear this midge obtained from the blossom of *Rorippa amphibia* both on the blossom of this plant and of swedes, and also midges from rape leaves on turnip, radish, swede and cabbage leaves as well as on the blossom of radish. The cross between midges obtained from *Rorippa* blossom and rape

leaves proved fertile, the offspring being reared successfully on turnip leaves and *Rorippa* blossom. It can therefore now be stated that *Contarinia nasturtii*, the swede midge, will both cause blossom and leaf damage on cultivated Crucifers and that only one species of midge is involved.

The general work on the biology of gall midges has continued; species on sweet chestnut, wheat, barley and among lettuce, poppy and Calendula seed having been reared and over 1,000 slides having been added to the collection. Volume 6 of Gall Midges of Economic Importance dealing with those attacking Miscellaneous Crops was published on 15th September, 1949. Mr. C. S. Tsi of the National Peking University spent the last month of the year studying gall midges with Dr. Barnes.

Slugs

The ecological investigations on slugs has mainly been concentrated on two particular lines. A nightly (for 214 successive nights and at intervals subsequently) study was made on a population of 1,000 individuals of the Grey Field Slug introduced into a garden where this species was previously absent although it was the dominant species in surrounding gardens. The study showed that this species of slug was able to maintain itself and breed successfully in this garden and that apparently its previous absence was probably due to the very great drying-out capacity of the soil (due to lack of humus). This lack has been diminished during recent years, but the drought of 1949 nearly caused a complete wipe-out again. This diminution in numbers during the summer and autumn of 1949 was also apparent in neighbouring gardens, although other slug species (perhaps thicker skinned) did not show a similar reduction in numbers due to the lack of moisture. This study also emphasized the differences in temperature in the various parts of a typical garden, under walls, plants, trees, etc., with the result that individual Grey Field Slugs were seen active on all but five nights during the winter of 1948-49.

The other particular investigation on slugs was a preliminary experiment in marking slugs by painting the shell of *Testacella* with cellulose acetate paint. Two groups were marked and such individuals were seen fairly regularly for about a month after marking but more infrequently later. One marked individual was, however, observed a year but a day after marking. If a satisfactory method can be found it will make possible studies of absolute populations.

Additional information was gathered concerning the life history, breeding, mating periods, etc. of several species of slugs.

Population Growth and Diurnal Periodicity of *Aphis fabæ*

Dr. Johnson reports that with two disc suction traps operating over a bean field and near a sugar beet crop, an hourly record has been obtained over a period of 6 weeks of the fluctuations in population and activity of the bean aphis and many other species. At the same time hourly records of wind-speed, temperature, hours of sunlight and rainfall have been taken. Together with these data the population growth on the crop has been studied and work

is in progress on the analysis of population and activity in relation to meteorological conditions.

Comparison of Traps

Further work on the comparative performances of sticky traps and suction traps was undertaken.

Movements of Insects in the Upper Air

It has been shown during 1948-1949 that the aerial tow-nets normally used for studies and in use also at Cardington are subject to very grave sampling errors. This has necessitated a revision of trapping methods particularly those in use at Cardington. Special suction traps have been designed and constructed which will be used for aerial-drift studies at Cardington in 1950.

Much of the time in 1948-9 was occupied in analyzing and writing up the work of the last three years.

Dr. Raw reports as follows:—

Chafers

A study of the ecology of the garden chafer, *Phyllopertha horticola*, which was begun at Bristol was completed after appointment to the staff at Rothamsted. A thesis embodying the results of this study was accepted by the University of London in June 1949 for the Ph.D. degree. This work is now being redrafted for publication.

Wireworms

The changes in wireworm population under leys are being studied in the ley and arable rotations experiments in Highfield and Foster's Field. These experiments enable the problem to be studied under a variety of leys on the same soil type beginning, in Highfield, with a relatively high population from the permanent grassland, and in Foster's Field with a low population from the old arable land.

In collaboration with the Insecticides Department, plots in the wireworm experiment on Hoosfield were sampled to estimate the effect of the chemical treatments on the wireworm populations. It was found that the wireworm population fell rapidly on all the plots during the course of the experiment and this, together with the practical difficulty of making an accurate estimate of a relatively low wireworm population on arable land, masked any treatment effect which may have occurred.

Earthworms

The cultures from the life history studies begun by Dr. A. C. Evans were kept going pending the appointment of a full time worker to continue the earthworm work. In the spring of 1949 Dr. Doeksen from Wageningen visited the Department and demonstrated an electrical technique for bringing earthworms to the soil surface. If this technique can be developed for quantitative work it will be a valuable aid to ecological studies.

In collaboration with Mr. Garner's Department, an exhibit on earthworms was staged at the Chelsea Flower Show in May 1949.

In August, 1949 Mr. J. E. Satchell was appointed to the department on an A.R.C. scholarship and will continue the work on earthworms, particularly the development of the electrical sampling technique.

Dr. G. Owen Evans reports as follows :—

TICKS

During the early part of 1949 the results of investigations on the ecology of *Ixodes ricinus* in Wales were prepared for presentation to the University of Wales for the degree of Ph.D. The thesis was successfully submitted in April and three papers on this work are now in press.

INVESTIGATIONS ON THE FAUNA OF FOREST SOILS

The major part of the field work has been conducted at the Forestry Commission's Nurseries at Ampthill, Bedfordshire. The chief project is the investigation of seasonal fluctuations in the soil fauna of a Spruce and Oak Forest. A study of this nature involves two fundamental problems, namely, the extraction and the identification of the fauna.

Extraction

A comparison of the Berlese and the Floatation Method, using 30 samples (soil and humus) 2 in. in diameter and to a depth of 3 in. from 4 sq. ft. of the floor of a spruce Forest, showed that there was no significant difference between the yields of arthropods above 0·5 m.m. in length. The Berlese technique was more satisfactory for smaller arthropods. This was probably due to the destruction of minute Acari during the washing process and the passage through the sieves (180 meshes to 1 in.) used in the floatation process. Extractions by the Berlese method from the Spruce stand in November yielded an estimate of 1,100 million arthropods per acre (to a depth of 3 in.) of which 330 million belonged to the Class Insecta and the remainder to the Arachnida.

Identification

The identification of the fauna presents one of the most difficult problems connected with faunistic surveys. A dearth of specialists in the field makes outside assistance limited. In the present studies Dr. Evans has concentrated on the Acarina (especially the Oribatidæ) which are the most numerous of soil arthropods. A large number of samples collected from various sites have yielded over 60 species of Oribatid mites. These have been identified and mounted for future reference. Dr. H. Gisin, Geneva, has kindly assisted in the identification of the Collembola.

BEE DEPARTMENT

By C. G. Butler

As in previous years several members of the department have read papers and given demonstrations at meetings of Scientific Societies, Beekeepers' Associations and other organisations. An Extension Course, arranged by London University, on the Physiology and Behaviour of the Honeybee was also given by Dr. C. G. Butler.

During the course of the last twenty-five or thirty years, very considerable advances have been made in the study of the sense-physiology and behaviour of the honeybee. As a result, numerous papers have been published in the world's scientific journals, and the need for some comprehensive account of the senses of the honeybee and the manner in which she uses them has become increasingly apparent. An attempt has been made to fill this want by the publication of a small book giving the results of some of the work (169).

Members of the department have continued to serve on various Committees such as the Bee Disease Advisory Committee, British Standards Sub-Committee for Beekeeping Equipment and the B.B.K.A. Research Committee. A new Bulletin on beehives has also been prepared for the Ministry of Agriculture and Fisheries.

Behaviour of Honeybee in the Field

Although the sense physiology of the honeybee has been extensively investigated, notably by von Frisch and his school, relatively little work has until recently been done on the way in which these senses are employed in the field, despite the fact that a sound knowledge of foraging behaviour is an essential preliminary to the properly controlled employment of the honeybee as a pollinating agent for fruit and seed crops.

Since 1939 a great deal of attention has been given by members of the department to this problem and as a result a number of papers have been published.

In 1943 Butler, Jeffree and Kalmus (J. Exp. Biol. **20**, 65–73) published the results of some work on the behaviour of marked honeybees when seeking sugar syrup from dishes and also when collecting nectar from various kinds of flowers. A large number of dishes were used in these experiments and were regularly arranged at twenty yard intervals from one another in a meadow. The data obtained confirmed and extended the work of earlier observers and indicated that once a honeybee has discovered a rich and abundant source of syrup or nectar at a particular site she tends strongly to confine her attention to this one site for hours and sometimes days on end; in the case of a dish of syrup to one particular dish and in the case of a plant to a definite and restricted area of the crop of flowers.

It was observed, however, that although this was the general rule there was, particularly when the supply of syrup in a dish failed or when the nectar supply in a group of flowers became diminished, a tendency for some of the bees that had been visiting a given dish or group of flowers with great regularity to visit neighbouring dishes or flowers. Since, however, the general tendency was clearly for a bee to confine her attention to a definite "foraging area"

little significance was attached at the time to the very small proportion of the total foraging population that was visiting a dish or group of flowers which strayed on to adjacent dishes or flowers. It was also found that when the bees were offered syrup of two different concentrations in dishes set out at random in a field the bees tended to congregate upon those dishes which contained the more concentrated syrup. Bees have frequently been observed at any given time to choose the species of flower which is yielding the richest nectar, and in 1945 Butler (J. Exp. Biol., **21**, 5–12), as a result of further work, reached the conclusion that nectar concentration determines in the first instance which species of plant will be visited in preference to others in flower at the same time in any given district, and that the abundance of the nectar then determines the proportion of the foraging population of a colony which will work the flowers with the richest nectar.

In 1949 Ribbands published the results of some observations on the movements of honeybees which were foraging in a specially planted garden. The bees were so marked that each individual could be readily recognised from all other individuals.

The garden contained five kinds of flowers which were arranged in long rows and large beds, and the visits of marked bees to individual flowers in this garden were very carefully noted. In one part of the garden there was a row of *Eschscholtzia* plants growing parallel to and only nine inches away from a similar row of *Limnanthes* plants. Both species were in flower at the same time and although the *Eschscholtzia* plants were taller than the *Limnanthes* plants, the flowers of both were intermingling to a considerable extent. Yet, despite the close proximity of these flowers to one another most of the bees visiting them worked one or other of them, completely ignoring the other. Two marked bees, however, were found to be working both crops, and one of these bees was watched for two consecutive days and each visit paid to each flower in the garden was recorded. At first this bee appeared to be visiting both kinds of flowers indiscriminately, later it was noted, however, that during the course of the morning the proportion of *Eschscholtzia* flowers visited per foraging trip was gradually increasing, the proportion rising from 37% on the second foraging trip of the day to 61% on the sixth trip. The process was then reversed and the proportion of *Eschscholtzia* flowers visited per trip fell rapidly and consistently, eventually falling to 0·2% on the last trip of the day. These changes in the proportion of *Eschscholtzia* and *Limnanthes* flowers visited per trip were accompanied by changes in the period of time required by this bee to collect a full load and it would appear to be likely that they resulted from changes in the relative attractiveness of the two crops.

These regular changes in the proportions of the flowers of these two species that were visited on each foraging expedition indicate that this bee was not foraging in a random manner but was making a series of definite choices, based, presumably, on her ability to appreciate changes in the relative attractiveness or food content of the flowers of these two species at different times of the day.

The increasing length of time spent by this bee on each successive foraging expedition throughout the day indicates that the *Limnanthes* flowers were becoming less and less productive, but the

single visits paid to *Eschscholtzia* flowers every now and again indicate that at each time of sampling the *Eschscholtzia* flowers were still found to be less attractive than the *Limnanthes* flowers. Ribbands pointed out that after only a single unsatisfactory visit to an *Eschscholtzia* flower the bee returned to the *Limnanthes* flowers ; each unsatisfactory visit to an *Eschscholtzia* flower appeared to reinforce the impression created on this bee by previous unsatisfactory visits to this species, with the result that the intervals between the occasional visits made to the *Eschscholtzia* flowers grew progressively longer. It would appear as though this bee was exercising both choice and memory, and that she was continually selecting the flowers of that species which was most satisfying to her at the time. Results illustrating similar behaviour on the part of other bees working in this garden were obtained.

It appears to be reasonably certain, therefore, that honeybees do not wander over a crop of different species of flowers at random, visiting first one species and then another, but rather that they quickly become accustomed to visit one particular species and a relatively small part of the total area occupied by a crop of flowers of this species. Every now and then, however, a bee will visit experimentally a few flowers of another species growing in the vicinity possibly only the flowers of one that is growing in the immediate vicinity, and, should it prove to be a more profitable source of food than that species, or, perhaps, than those species, which she has visited hitherto, each bee will select for herself a foraging area on the crop of this new species of flower and will remain faithful to it just so long as she does not discover, during one of her experimental visits, an even more profitable source of food elsewhere.

Recently Miss G. Wykes has been attempting to determine whether the variations which are known to occur in the composition of the total sugar content of floral nectars influence the preference shown by the honeybee for the nectar of one species of flower over that of another. Equal volumes of solutions of the same concentrations, but differing in constituent sugars, were offered to bees in the field and the preferences of the visiting bees noted. It was found that at the concentration of the solutions that were offered a significant preference was shown by the bees for a solution containing sucrose, glucose and fructose in the proportions 1 : 1 : 1, in comparison with any solution of the individual sugars, or of mixtures of these sugars in various proportions. This result appears to be of some biological significance since nectar, the natural source of carbohydrate for the bee, normally consists of a mixture of these three sugars, possibly in certain cases in the proportion 1 : 1 : 1.

This investigation is being continued in the laboratory and similar results to those in the field have been obtained, but further experiments have shown that the relative sweetness to the honeybee of the various sugar solutions almost certainly varies with their concentration, as is the case in man.

During the last few year Butler has been investigating the method by which a scout bee, that is to say a bee which leaves her hive without any preconceived ideas of where she is going to seek food or with what perfume it is associated, finds a new source of food. He has found that the honeybee is attracted to any area in

which a strong floral perfume, such as oil-of-lavender, is present, and that she then tends to seek nectar from any small crevices in any small coloured, preferably patterned and moving, object, such as a disc of coloured paper, in this area.

Once a scout bee has been led to a source of food by the presence of a strong floral perfume, followed by colour or pattern, she samples the contained food and should it prove profitable to work, that is if it is both rich and abundant enough to satisfy her, she returns to her hive, and by means of the " dance language " discovered by von Frisch, quickly recruits further bees to work the source that she has discovered.

The Effects of Anaesthetics upon Foraging Behaviour

C. R. Ribbands has continued his work on the effect of various anaesthetics upon the foraging behaviour of bees, and a paper on this subject will be published shortly (167).

He has demonstrated that anaesthesia with chloroform does not either impair the memory, influence the foraging behaviour or reduce the longevity of honeybees. On the other hand, anaesthesia with carbon dioxide, although it does not impair the memory of treated bees, does result in a permanent change in their behaviour but has no direct effect upon their longevity. The pollen collecting activities of bees treated with carbon dioxide are either eliminated altogether or very markedly reduced. Similarly the treatment of newly emerged bees with carbon dioxide results in the elimination of all or most of their brood rearing and wax secreting activities and causes them to commence to forage at an early age. Since foraging life is necessarily more hazardous than life within the hive, the expectation of life of bees that have been treated with carbon dioxide is less than that of control bees that have not been treated in this way.

The effects of anaesthesia with nitrogen are similar to those obtained with carbon dioxide. It would appear likely, therefore, that temporary oxygen lack is the factor which results in the changes of behaviour mentioned.

Attempts are being made in the laboratory to study the physiological effects of anaesthesia with carbon dioxide on honeybees, and an attempt to discover the fundamental nature of the basis of the division of labour exhibited amongst the worker bees of every colony. Little success has been achieved so far, however.

Pollen Trapping

The regular routine trapping of samples of pollen which has been carried out for several years by means of pollen traps placed on the entrance of hives containing normal colonies of bees has been discontinued for the time being.

Although this technique is undoubtedly a useful tool for the elucidation of certain specific problems it appears doubtful whether routine trapping, with the heavy labour of sorting the catch into its constituent pollen species, will yield further results of major importance unless some method can be devised to overcome some of the errors inherent in the present apparatus. The pollen traps so far devised are all of the same basic design and suffer from the serious disadvantage that they trap a higher proportion of the larger sized

pollen loads. It is characteristic of some plant species that bees only collect very small loads of pollen from them and these loads, although they may in the aggregate be extremely important in the economy of a colony are almost entirely missed by the present traps.

J. Simpson has further elaborated his keys, based on those worked out by Miss A. D. Synge when she was a member of the department, for the identification of the pollens of British plants visited by bees. These keys are, together with the fairly extensive pollen collection, in constant use in the department and are thus being subjected to considerable testing. It was hoped that it might prove to be possible to publish a monograph on the identification of the pollens of bee plants occurring in Britain, but the heavy cost of reproduction of the necessary photomicrographs appears to make this impossible, at all events for the time being.

Bee Breeding and Strain Trials

The development of the technique of artificial insemination of queen honeybees has been continued, and certain small advances have been made. Much work still requires to be done on the study of the sexual development of drones, however.

Between June 9th and August 20th, 191 queens were inseminated and, on account of various accidents such as the destruction of a large batch of queens early in the season by overheating with a microscope lamp, less than 50 per cent were wholly successful. None the less 43 queens of various strains which it was desired to test were introduced into colonies in out-apiaries and continued to lay well and produce satisfactory brood. The development and behaviour of these colonies will be studied in detail during 1950.

During 1949 the development and behaviour of the inseminated queens of different strains introduced in the summer of 1948 into nuclei in one of the out-apiaries was studied and some useful information obtained. Some of the colonies headed by these queens did remarkably well, and the difference observed between the different strains of bees in the apiary was well marked.

Work has been commenced in an attempt to distinguish biometrically between the different strains of bees maintained by the department. Since the production by means of instrumental insemination of the large number of queens necessary for strain trials is an extremely tedious business, it is hoped that it will prove to be practicable to mate large numbers of queens with selected drones in normal queen-mating apiaries and, by studying the biometrical ratios of the offspring of queens mated in this way, to be able to select those queens that have mated with the drones desired.

Instrumental insemination will, of course, continue to be employed for the production of breeder queens.

Nectar Secretion

Miss G. Wykes has continued her work on the influence of the available supplies of carbohydrates on the process of nectar secretion by various flowering plants. By placing flowers of the same age in feeding solutions of varying sucrose content she has found that with increasing concentration of the feeding solution, up to about 20 per cent., there is a proportionate increase in the concentration of the nectar secreted by the flower and in the total amount of sugar

secreted. No significant differences were observed when the feeding solutions consisted of glucose, fructose or sucrose of the same concentration. By means of ringing and defoliating experiments with the flowering shoots of horse-chestnut and apple trees it was shown that interference with the normal carbohydrate supply either before or during the flowering period, results in a partial reduction, or total cessation, of nectar secretion.

An attempt has also been made to determine the possible effects of insect visits on nectar secretion. Preliminary results suggest that frequent withdrawal of nectar from a flower by insects tends to stimulate the secretion of further nectar.

Syrup Feeding

J. Simpson is investigating the composition of the stores of "honey" resulting from the autumn feeding of sugar syrup to colonies of bees. A few analyses undertaken in 1948, and the results so far obtained in the examination of a more extensive series of samples resulting from 1949 feeding, have shown that "honey" produced from autumn fed sugar syrup has a somewhat lower water content, and a very much higher sucrose content than normal floral honey. These results were obtained when both concentrated and dilute syrup was fed and whether feeding took place early or late in the season.

Humidity in the Winter Cluster

J. Simpson has now completed a paper on the humidity of the atmosphere within a winter cluster of honeybees (169), and has found that variations in the atmospheric conditions outside the hive have little effect at normal winter temperatures on humidity within the cluster. He has also continued his previous work on the water balance of the individual honeybee by making use of Dixon's constant pressure modification of the Barcroft respiratory manometer to measure the loss of water by individual bees.

It is felt that the results so far obtained require confirmation by other methods, but they suggest that bees are unable to compensate for variations in atmospheric humidity by control of the evaporation of water from their bodies, and that when a honeybee is in a state of rest very little of the water lost passes through the spiracles.

Nosema and Amoeba Diseases

H. Hassanein has continued his work on the development of these diseases in the adult honeybee and on their influence upon the behaviour of infected individuals.

European Foul Brood Disease

Mrs. Schreiner (Miss E. Kops) has continued her attempts to repeat the observations of Professor R. Burri of the Liebefeld Institute, Berne, on the *Bacillus eurydice, Bacillus alvei, Bacillus pluton* complex. So far no results similar to those reported by Professor Burri have been obtained and in no case so far has *B. pluton* been recognised in a pure culture of *B. eurydice*.

(This work, since Miss Kops' marriage, has been transferred to Cambridge for the time being.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

By C. Potter

The only change in the scientific staff of the department consisted of the appointment of Mr. P. Burt as research entomologist. During the course of the year Mr. A. H. McIntosh was awarded the Ph.D. degree of London University.

The lack of accommodation and in particular lack of facilities for providing controlled environments was felt even more severely than in previous years, but deficiencies in equipment, have, to a very large extent, been remedied.

The central theme of work of the department continues to be the laboratory study of the factors that affect the susceptibility of insects to insecticides. In addition some special studies have been undertaken and some field experiments carried out.

Chemical

Analytical chemistry

Rotenone. During the year a series of analyses were made on a sample sent in by the Board of Greenkeeping Research.

Pyrethrum. (a) World wide collaborative analysis of pyrethrum flowers. Assistance was given by the department in the preparation of a report on this subject, based on the work carried out in the previous years. (b) Colour reaction. It was observed that a colour reaction of carboxylic acid derivatives was also applicable to the pyrethrins.

Hexaethyl tetraphosphate. Estimations of the tetraethyl pyrophosphate content of samples of hexaethyl tetraphosphate were carried out using the method of Jacobson and Hall as modified by Albright and Wilson to avoid interference due to added materials.

Physical chemistry

The effect of particle size of suspensions of contact insecticides on their toxicity as contact poisons. This work has been continued mainly in order to try to explain why D.D.T. in the form of large crystals is easily taken up through the insect cuticle and crystalline rotenone, under the same conditions is not.

It is supposed either that D.D.T. is considerably more soluble than rotenone in the outermost (wax) layer of the insect epicuticle or that the critical particle size, under which solubility becomes greater than normal, is different for D.D.T. in wax than for rotenone in wax. On this basis it would be expected that at a low temperature after treatment, small particles of D.D.T. would be more toxic, relative to large, than at a higher temperature after treatment.

Experiments have been carried out which show that this is so. D.D.T. needles (350μ) are about five times as toxic to adult *Tribolium castaneum* Hbst. as D.D.T. colloid when the insects are kept at 25°C. after treatment, but at 11°C. the colloid is about twice as toxic as the needles. With adults *Oryzaephilus surinamensis* L. as test subjects the results are more marked. Part of this work has been published. Further experiments along these lines are contemplated.

Surface active agents. The work started in 1946 on the effect of surface active agents on the behaviour of chemicals applied as contact insecticides in aqueous medium is being continued. No consistent large differences in the toxicity of the insecticide due to different surface active agents has as yet been found, but differences up to three or four times may occur. Differences in the surface active agent used may affect considerably the physical state of the deposit of insecticide. This work is being continued.

Biochemical

The survey of the effects of insecticides on the oxygen uptake of insects has been continued and a paper describing the experimental technique devised and some of the results obtained has been accepted for publication.

Preliminary work on insect esterases has been carried out, and extracts of the mealworm *Tenebrio molitor* both adults and larvæ, and of the flour beetle, *Tribolium castaneum* Hbst. adults have been shown to hydrolyse rapidly ethyl butyrate and o-nitrophenyl acetate. Extracts of adult *T. castaneum* did not appear to show any activity in the hydrolysis of acetyl choline.

Some work has been done on the capacity of organo-phosphorus compounds used as insecticides to inhibit the activity of these insect esterases. The hydrolysis of o-nitrophenyl acetate is inhibited by E. 605 (O.O. diethyl-o-p-nitrophenyl thionophosphate) and H.E.T.P. (Hexaethyl tetraphosphate). At pH 6·5 and 25°C. the concentration required to give 50 per cent. inhibition is approximately 10^{-7} M for E. 605 and 10^{-8} M for H.E.T.P. when estimated on the basis of the presumed active constituent—tetraethyl pyrophosphate. An attempt is being made to integrate this work on the mechanism of action of poisons with that on bioassay methods as outlined in the section on bioassay. It is proposed to continue the work both on the effect of poisons on the oxygen uptake of insects and on insect enzyme systems.

Synthetic organic chemistry

Work is proceeding on the synthesis and reactions of keto-alcohols related to the pyrethrins.

The aim of the work under this heading is the study of the relationship between molecular constitution and configuration and insecticidal activity. The work is at present confined to the pyrethrins. Contact has been established with Dr. F. B. LaForge in the Bureau of Entomology and Plant Quarantine, U.S.A., and collaboration established with Dr. S. H. Harper in England. An account of a toxicity study of two compounds closely related to the pyrethrins obtained by the courtesy of Dr. LaForge is given in the bioassay section.

Bioassay

Organo-phosphorus compounds

Insecticidal activity of E. 605, T.E.P.P. and H.E.T.P. Following up work done in the previous year additional laboratory tests of insecticidal activity of samples of E. 605 (O.O. diethyl O.p. nitrophenyl thionophosphate), H.E.T.P. (Hexaethyl tetraphosphate) and T.E.P.P. (Tetraethyl pyrophosphate) were carried out.

The materials were tested for their effect both as contact and

stomach poisons and some preliminary experiments made on their ovicidal effect.

Contact effects

Larvæ of *Plutella maculipennis Curt.* (Diamond back moth), E. 605 (M.L.D. 0·0055% w/v) was approximately six times as toxic as T.E.P.P. (40% Tetraethyl pyrophosphate) (M.L.D. 0·035% w/v). When measured at LD50 level, D.D.T. (M.L.D. 0·00386% w/v) was slightly more toxic than the E. 605.

Adults of *Phaedon cochleariae* (Mustard Beetle). E. 605 (M.L.D. 0·00615% w/v) was twenty-five times as toxic as T.E.P.P. (40% Tetraethyl pyrophosphate) (M.L.D. 0·0153% w/v) measured at LD50 level.

The T.E.P.P. was approximately sixteen times as toxic as nicotine (M.L.D. 0·234% w/v).

Adults of *Tribolium castaneum* Hbst. (Flour Beetle). E. 605 (M.L.D. 0·000775% w/v) was twenty seven times as toxic as T.E.P.P. (40% Tetraethyl pyrophosphate) (M.L.D. 0·0211% w/v) forty four times as toxic as H.E.T.P. (15% Tetraethyl pyrophosphate) (M.L.D. 0·0342% w/v).

Stomach poison effects

Strips of food leaf bearing known doses of insecticides were fed to the last instar larvæ of *Diataraxia oleracea* (Tomato moth).

The figures for the M.L.D. were taken from the provisional probit lines and were estimated in terms of mg. per larva, the larvæ being approximately 0·4 gm. each.

E. 605 (commercial sample) 0·0035–0·0045 mg., T.E.P.P. (75% Tetraethyl pyrophosphate) 0·070 mg., lead arsenate (99% pure) 0·075–0·090 mg., D.D.T. (pure p.p. 'isomer) 0·012 mg. Thus E. 605 was the most toxic, being approximately three times as toxic as D.D.T. and about twenty times as toxic as T.E.P.P. and lead arsenate.

Ovicidal effects

Preliminary tests were carried out with E. 605 and T.E.P.P. on the eggs of *Diataraxia cleracea* (Tomato moth), *Plutella maculipennis* (Diamond back moth) and *Oligonychus ulmi* (Fruit tree red spider).

E. 605 showed high ovicidal effect to the lepidopterous eggs at concentrations from 0·1% w/v to 0·01% w/v but the T.E.P.P. showed little or no toxicity at the same concentrations. Variable results were obtained with E. 605 on the red spider eggs, in one test it appeared to be less toxic than D.N.O.C. at 0·1% w/v. T.E.P.P. showed no action until the concentrations were raised to 0·8% w/v when there was some evidence of toxicity.

Relationship between the tretaethyl pyrophosphate content of H.E.T.P. and its insecticidal and anti-esterase activity

It has been stated that the insecticidal activity of H.E.T.P. is entirely due to tetraethyl pyrophosphate present in it. A series of samples of H.E.T.P. were received from Messrs. Albright and Wilson, with a request that their insecticidal activity should be investigated. It was decided to carry out this work and at the same time to determine what correlation, if any, there was between the insecticidal activity of the samples, their content of tetraethyl pyrophosphate and their capacity to inhibit the esterase activity. The esterase was

obtained from larvæ of the mealworm (*Tenebrio molitor*).

It is proposed to do some more work on this subject and to publish a full account later.

From the figures already obtained it would appear that while the tetraethyl pyrophosphate content gives some indication of both insecticidal activity and of anti-esterase activity, other active components are present in the mixtures.

The possibility of using anti-esterase activity as a method for the estimation of insecticidal potency of samples of organo-phosphorus compounds of similar constitution is under consideration.

N Isobutylamides

At the request of the Agricultural Research Council three amides of structures related to that proposed for Herculin (an insecticidal material isolated from prickly ash bark) which had been synthesized by Drs. Raphael and Sondheimer (Nature, 1949, **164,** 707) were tested for their activity as contact insecticides.

Materials

A. $C_3H_7CH\overset{cis}{=}CH(CH_2)_4CH\overset{cis}{=}CO.NH.CH_2.CH<\begin{matrix}CH_3\\CH_3\end{matrix}$

B. $C_3H_7CH\overset{cis}{=}CH(CH_2)_4\ C\equiv CO.NH.CH_2.CH<\begin{matrix}CH_3\\CH_3\end{matrix}$

C. $C_3H_7C\ =\ C(CH_2)_4\ C=CO.NH.CH_2CH\ <\begin{matrix}CH_3\\CH_3\end{matrix}$

The materials were tested on apterous, viviparous, parthenogenetic females of *Macrosiphum solanifolii* (potato aphid), fully grown larvæ of *Plutella maculipennis* (diamond back moth), and adult *Phaedon cochleariæ* (mustard beetle). None of the materials showed any appreciable toxicity at concentrations ranging from 0·5%–0·005% w/v when applied in aqeous medium containing 10% w/v acteone and 0·1% w/v sulphonated lorol.

Synthetic compounds allied to the pyrethrins

The announcement by Dr. LaForge and his colleagues of the synthesis of highly active esters of similar constitution to the pyrethrins was of special interest to us, since work was in progress in the department on the relationship between the chemical structure and biological activity of the pyrethrins and similar molecules.

By the kindness of Dr. LaForge and of the Chemical Biological Co-ordination Committee of the National Research Council of America, we obtained samples of the esters of (±)–3–methyl–2–allyl–cyclopent–2–ene–4–ol–1–one with the natural (+)–trans– and the synthetic (±)–cis–trans–chrysanthemum monocarboxylic acids.

The toxicity of these two esters as contact insecticides was compared with that of an extract of pyrethrum flowers to four insect species. It was found that both the absolute and relative toxicity of the materials varied with the species of insect used. The compound with the natural acid and synthetic alcohol varied from about four times the toxicity of the natural pyrethrins to the larvæ of the diamond back moth (*Plutella maculipennis*), to about one eight as

toxic to the adult apterous viviparous females of the potato aphid (*Macrosiphum solanifolii* Ashm.). The fully synthetic material varied from approximately twice as toxic as the natural pyrethrins—test subject, *Plutella maculipennis* Curt., to approximately one sixteenth as toxic—test subject *Macrosiphum solanifolii*.

This variation in relative toxicity with the species of insect used as test subject is interesting since the compounds are chemically closely related. The variation in relative toxicity with test subject is further illustrated since the ester with the natural acid is approximately as twice as toxic as the ester with the synthetic acid to three of the test subjects, but was about 4/5 as toxic to the fourth. These specific variations render the task of relating molecular structure and configuration to toxicity difficult.

Biological

Bioassay techniques

A micropipette has been constructed for the injection of small quantities of insecticide into the body cavity of insects. The design of the pipette is based on the Gilmont ultra-microburette and the Heal and Menusan injection pipette. A mechanical manipulator for holding and positioning the insect for injection has also been built, to work in conjunction with the pipette. No other apparatus for precision injection has so far been described, and, in addition to its use for the study of the action of insecticides, it is proposed to study the various factors involved in injection techniques which influence the results of the experiments.

During the course of the year some advances have been made in the decision of the atomizing nozzle and other parts of the Potter spray tower. Some work has also been done on the relative importance of the direct contact effect on the body of the insect and the residual film effect using this technique normally employed with this instrument. In general the results are an estimate of the sum of the two effects. It appears that, in some instances, at least, an exposure to the film alone gives a higher toxicity than direct contact on the body of the insect alone.

The effect of stage development on resistance

Using the tomato moth (*Diataraxia oleracea*), the mealworm (*Tenebrio molitor*), and the cockroach. (*Periplaneta americana*) with D.D.T. and pyrethrum as insecticides, a study has been made of how resistance varies with the stage of development. Large differences in resistance, between different instars of a given species have been found, and even within a given instar these differences may be considerable.

Persistence of insecticides on foliage

Work on this subject has been in progress in the department for some time and has now been intensified at the request of the Colonial Insecticides Committee, which is providing additional finance.

Preliminary experiments on the persistence of D.D.T. on foliage which were carried out during previous years has been followed up in greater detail in 1949. Using turnip and cabbage foliage and a number of different formulations it was found that the type of foliage (sp. of plant) and the nature of the spray medium have a considerable effect on the toxicity of residual films of D.D.T. Using

D.D.T. in simple crystalline suspension it was shown that on cabbage leaves the residual films rapidly lose their effectiveness as a result of attenuation of the deposit due to plant growth. Under these conditions loss of D.D.T. due to sunlight and rainfall is of negligible importance. It was found, however, that within two days after treatment and before a significant amount of leaf growth had taken place noticeable changes had taken place in the effectiveness of the deposits. There was a reduction in toxicity to insects which only walk the surface but do not eat the leaf and an increase in toxicity to insects that eat the leaf as well as walking the surface. Chemical analyses showed that over a period of one month there was no loss of D.D.T. films on cabbage provided the plants were not exposed to rainfall or to short wave ultra violet light.

Natural fluctuation in the resistance of insect populations and effect of host plant on resistance

Very little work was done on these subjects owing to difficulties with the aphid, mainly due to attacks by parasites and fungal disease.

Mechanism of selection of resistant strains of insect

Some work preparatory to a study of this subject has been carried out. Selected strains of *Drosophila melanogaster* are being reared of known genetical constitution. Spraying techniques for use with these insects are being elaborated and methods for the permanent preparation of individual specimens have been studied so that any differences that occur before and after treatment may be compared.

Effect of environment on the toxicity of contact insecticides

Work on this subject is being continued.

Insect rearing

The twenty five insect species listed in the 1948 report have all been reared during the present year. In addition stocks of *Locusta migratoria* (African migratory locust) and *Pionea forficalis* (Garden pebble moth) have also been reared. A particular study has been made of the biology of *Diataraxia oleracea* L. (Tomato moth) and *Phaedon cochleariæ* F. (Mustard beetle), which have proved to be among the most satisfactory test subjects.

A great deal of trouble has been experienced during the current year with the aphid stocks due to parasites and fungus disease and probably other factors. It has not so far been possible to work on improvements of the rearing technique but this will be done as opportunity offers.

Studies on insect diapause

Some work has been done on the factors influencing the diapause in mustard beetle and tomato moth since this is a major factor when considering rearing techniques.

The mustard beetle overwinters as a resting adult. This can be activated and induced to oviposit within a few days by placing it in a temperature of 30°C. At 12–24°C. activation does not occur or is delayed unless the insect is subjected to 16 hours light per 24 hours. It was found with tomato moth that climatic conditions during the larval instar alone are responsible for inducing or preventing diapause in the pupa. Sixteen hours light per 24 hours prevents diapause

except at low temperatures (12°C.). Eight hours light per 24 hours induced diapause except at high temperatures (34°C.).

Field Experiments

Control of wireworms

The experiment started in the autumn of 1947 was continued in order to study the residual effects of the various treatments. In addition, a part of the experimental area was set aside for testing possible tainting effects, resulting from the treatments with benzene hexachloride. Judging on crop yields it was found that the autumn 1947 treatments of benzene hexachloride (12–14% gamma isomer) broadcast at 7·9 lb. crude B.H.C./acre, benzene hexachloride drilled with the seed at 2·9 lb. crude B.H.C./acre and D.D.T. drilled with the seed at the rate of 7·2 lb./acre had the greatest residual effect, with yields of 39·6, 37·3 and 36·4 cwt./acre respectively in 1949. The soil fumigants ethylene dibromide and D.D. had less residual effect, applications of 45·5 lb./acre of ethylene dibromide and 120 lb./acre of D.D. in 1947 giving yields of 34·1 and 31·8 cwt./acre in 1949. Seed treatment had no residual effect. The control yield was 28·4 cwt./acre. Taking into account the previous year's results it would appear therefore, that the treatment where benzene hexachloride was drilled with the seed and broadcast gave good immediate results and good residual effects, ethylene dibromide and to a lesser extent D.D. gave good immediate results and fair residual effects, seed dressing with high gamma isomer B.H.C. gave good immediate effects and no residual effects and D.D.T. gave poor immediate effects but good residual effects. Evidence was obtained that there was a risk of taint occurring in root crops planted in soil previously treated with crude Benzene hexachloride at dosages from 0·98–5·92 lb./acre.

Control of flea beetle

A large scale experiment on the use of benzene hexachloride, D.D.T. and E. 605 to control flea beetles failed owing to lack of attack, but small scale trials indicated that benzene hexachloride sown with the seed might give good protection. It is hoped to follow up this work.

Control of aphids carrying virus on potatoes

In collaboration with the Plant Pathology department a preliminary experiment was carried out on the control of aphids carrying virus in potatoes. The results of this experiment are not yet available.

FIELD EXPERIMENTS

By the Plot Committee

Field Experiments at Rothamsted and Woburn

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments : E. M. Crowther (Chairman), H. V. Garner (Secretary), H. H. Mann, J. R. Moffatt, D. J. Watson, F. Yates.

The number of plots handled by the Field Staff at Rothamsted and Woburn were as follows :—

	Grain	Roots	Hay	Grazing	Total
Classical Experiments					
Rothamsted ..	121	72	47	—	240
Woburn	24	—	—	—	24
Modern Long-Term Experiments					
Rothamsted ..	279	232	84	32	627
Woburn	149	218	31	12	410
Annual Experiments					
Rothamsted ..	489	208	12	—	709
Woburn	—	—	—	—	—
Total					
Rothamsted ..	889	512	143	32	1,576
Woburn	173	218	31	12	434
Grand Total ...	1,062	730	174	44	2,010

Note : Grain includes cereals, beans, peas, linseed. Roots include potatoes, sugar beet, mangolds, cabbage, leeks. Hay includes lucerne and cut grass.

One experiment of 40 plots on winter beans on Stackyard Field could not be drilled owing to the wet state of the ground in late autumn and was abandoned, so the number of plots actually harvested on the two farms was 1970.

The season 1949 was remarkably dry, mild and bright. Every month from January to September inclusive was below the average in rainfall, and there had been no excess of rain at the end of 1948. There was very little severe frost in the winter, and practically no snow. The characteristics of the season and the effects of the weather on crops are fully described in the section of this report dealing with the Rothamsted and Woburn farms.

In the year under review the classical and long-period experiments were continued. Most of them have already been summarised in recent Reports.

Ley Arable Experiment, Rothamsted

The general purpose and the scheme of treatments of the new ley arable experiments at Rothamsted were given in the Report for 1948, p.98.

The first year of this elaborate and exacting experiment has been used in developing the technique. Wheat was grown on two blocks on Highfield and two on Fosters. On Highfield where the wheat was drilled on recently ploughed old turf, the plant came well but went off badly during the winter and looked very poor indeed at the turn of the year. Later earth nut (*Conopodium denudatum*) appeared as a

serious weed in the crop and was considerably reduced by dusting with M.C.P.A. weedkiller. The crop then improved a little and yielded 15·6 cwt. grain per acre. There were no visible effects due to the different levels of nitrochalk on the sub-plots. On Fosters the wheat was earlier sown and looked distinctly better, the effect of added nitrogen was also slightly greater than on Highfield. The mean yield was 23·3 cwt.

All leys and legumes were sown in the open ground in the spring of 1949. Conditions were by no means ideal as the seedbeds were very dry ; nevertheless the take was reasonably good, with lucerne as the best-looking patches on both fields, though some of the leys and reseeded grass (identical at this stage) looked fresh and covered the ground well. As the dry weather persisted in early summer all young sowings had a great struggle with strong-growing weeds, thistles on Highfield, " knotgrass " (*Polygonum aviculare*) on Fosters. The " knotgrass " dominated the leys so badly in early autumn that the plots were sprayed with sulphuric acid which clearly shifted the balance in favour of the grass.

Grazing by sheep was reduced by the very dry weather to only two rounds per plot in 1949, and the established grass land in Highfield did no better than the new stands. There were two cuts of cut grass on Highfield, but only one on Fosters. Lucerne gave one light cut on each field. By late summer everything except the lucerne was badly burnt up. The season was used to develop a grazing technique. Temporary post and netting fences were tried but did not hold the stock, particularly when an enclosure was grazed right down and the animals were hungry. These fences will be replaced in future by wheeled iron hurdles, a type that has been used successfully at Woburn for a similar purpose.

Spring-sown Cereals

For the past three seasons four kinds of cereal crops have been compared for spring sowing. The experiments were located in a different field each year. The crops were : Star oats, Atle wheat, Bersee wheat, and Plumage Archer barley. All crops were tested at several nitrogen levels, sulphate of ammonia being applied at 0, 0·3, 0·6, 0·9 cwt. N. per acre. Superphosphate and muriate of potash were also tested. The mean results over the three years were as follows :—

Mean Yields and Responses: cwt. per acre 1947-49

Fertilizers	Grain				Straw			
	Oats	Atle	Bersee	Barley	Oats	Atle	Bersee	Barley
0·0 cwt. N	16·4	18·6	19·2	23·5	33·2	28·4	27·5	25·5
0·3 „ „	20·9	21·5	23·8	27·3	38·9	34·2	34·4	31·1
0·6 „ „	22·3	23·0	24·3	28·4	39·2	37·9	38·9	35·0
0·9 „ „	23·3	22·8	25·3	27·7	40·7	38·7	40·8	36·0
Mean	20·7	21·4	23·2	26·7	36·0	34·8	35·4	31·9
Response to Superphosphate ..	1·6	—0·6	—0·3	0·8	0·4	0·1	0·3	0·8
Response to Muriate of Potash ..	—0·3	—0·4	1·2	1·8	—0·6	0·4	—0·1	1·2

In grain production barley stands well above the other spring-sown cereals at all levels of nitrogenous manuring. On the average oats and Atle wheat each yielded 6 cwt. less than barley, and spring sown Bersee wheat about 3½ cwt. less. In these three experiments Bersee wheat sown in the spring gave somewhat higher yield than Atle though it was later to ripen. All the cereals responded well to nitrogenous dressing, but all showed a marked falling off in response at the higher levels. Thus the first 1½ cwt. of sulphate of ammonia produced a mean increase over all crops of 4 cwt. of grain. When the dressing of sulphate of ammonia was raised to 3 cwt. per acre the further increase was only 1 cwt. grain while 4½ cwt. of sulphate of ammonia gave practically the same yield as 3 cwt. There was no very marked difference between the behaviour of the different crops in their responses to nitrogen, oats were perhaps slightly more responsive than barley at all levels; the wheats being intermediate. The level of yield and responses to nitrogen varied with the season, in particular in the abnormally dry season 1949 the nitrogen responses were lower than in the other two more favourable years.

The responses to phosphate and potash were much smaller than to nitrogen. Oats gave significant responses to phosphate in two years out of the three; the yield of Bersee wheat and barley was slightly increased by potash.

The nitrogen responses in the straw were larger than the corresponding grain responses, and though they fell off somewhat at the higher levels they showed less curvature. In the moist season 1948 oats and barley produced about 6 cwt. more straw and wheat from 12-17 cwt. per acre more than in the dry years. In wheat and barley the responses to nitrogen were bigger and more sustained in the wet season than in the dry ones. Phosphate and potash had very little effect on straw yield. The biggest increase, 1·2 cwt. per acre, was produced by muriate of potash in the straw of barley.

The Annual Experiments of 1949

The following brief notes deal with the main points arising from those annual experiments of 1949 which do not belong to larger series of experiments or are not reported elsewhere by the departments specially concerned.

Potatoes

There were three annual experiments on potatoes:—(1) Four levels of farmyard manure applied in three different ways, in presence and absence of each of the three main nutrients, N, P, K. This experiment was carried out on Sawyers III. The dressings of dung were 0, 5, 10, and 15 tons per acre and these were applied either ploughed-in in winter, or ploughed-in in spring, or spread in the ridges in spring. The whole experimental area was ploughed both for the winter and for the spring application. The potatoes without dung gave 5½ tons of potatoes; on the average of all methods of application dung increased the crop by ½ ton for each 5 tons applied, the effect being practically linear up to the maximum dressing. The three methods of application give closely similar results on the average of all rates. Since no adjustment was made

for loss during storage the spring applications were derived from rather heavier amounts of dung than were actually applied in the winter dressings. A fuller examination of this experiment will be made when the response curves are available for each method of application. Potash was the most effective supplementary nutrient in the absence of dung but the responses were steadily reduced almost to zero as the dressings of dung were increased. Nitrogen gave good effects even in the presence of dung. (2) Time of planting experiment, Sawyers III. This has now been tested on a different field each year for several seasons. The earliest planting on March 29th gave a yield of 5·4 tons which fell to 4·5 tons for the latest planting on May 30th, the other plantings being intermediate in yield. Dung gave a response of 2 tons per acre which was practically independent of the date of planting the potatoes. Nitrogen with a mean increase of 0·7 tons and potash with a mean increase of 0·5 tons were distinctly more effective on the earliest planting than on the rest. As usual there was a negative interaction between dung and potash. The above experiment was used by the Plant Pathology Department for observations on the spread of virus diseases and will be more fully reported by them. (3) Methods of planting potatoes, Great Knott III. Arising out of the remarkably rapid increase in the mechanical planting of potatoes, a start was made in 1949 in testing different methods of placing the tubers and applying the fertilizers. The standard method of applying fertilizers down the ridges followed by hand planting gave significantly lower average yields than planting by the dropper either on the flat or in the ridges. The seed was infected with 'dry rot' and although it was carefully sorted it is possible that some diseased tubers were planted. The loss of plant due to this cause would probably be more severe on the dried-out open ridges which were hand-planted than on either of the other methods where the sets were put straight into moist soil. Fertilizer application at 8 or 16 cwt. per acre gave very small increments in yield in this experiment so the comparison of different methods of incorporating the artificials led to no clear results. The experiment will be repeated for several seasons.

Linseed. Great Knott I. An experiment was put down to test combine drilling of PK fertilizer against the same fertilizer broadcast. The material was used in granular and also in powder form, each at single and double rates per acre. Sulphate of ammonia was also tested. The plant was good and even but the plots were badly infected with Fat Hen early in the summer. This was well controlled by spraying with liquid "Agroxone" but the yield of the crop was probably reduced by weediness and drought so that finally poor yields of only about 4 cwt. of seed per acre were obtained. Under these circumstances the only definite result was a reduction of yield when the heavy dressing of fertilizer was put in with the combine drill. Thus 6 cwt. of fertilizer broadcast gave 4·5 cwt. grain and 7·9 cwt. of straw; if drilled-in the yields were only 3·3 cwt. grain and 4·9 cwt. straw. There was no certain difference between powder and granular fertilizer.

Spring bean varieties

Four Dutch varieties of spring beans were compared with five English and Scottish strains at three seed rates (1, 1½, and 2 units).

The rates were calculated to provide equal numbers of seeds per acre. This involved seedings by weight varying from 0·8 to 2·5 cwt. per acre at the lowest rate. Yields of all varieties were light. They ranged from 5·3 cwt. for a Dutch Pigeon bean to 12·5 cwt. for an Essex strain of horse bean. The English strains from the National Institute of Agricultural Botany, and a strain of Scotch Mazagan bean gave higher yields than the Dutch horse beans, particularly at the lower seed rates. Practically all varieties gave profitable increases for increased seed rates in the sense that the increase in grain yield was usually about twice the weight of the extra seed sown. One Dutch variety of Broad beans with very large seeds failed to justify the heavier seed rates.

Other experiments

In addition to the above experiments, the following were conducted either as part of a series or specially for departments who will report the results elsewhere. (1) Placement experiments on threshed peas and spring beans. Broadcast application of PK fertilizer at several rates compared with fertilizer placed by a special experimental drill (2) Experiments on wheat, Little Knott. Agricultural conditions affecting the incidence of eyespot disease. Tests of seed rate, level of and time of application of nitrogen top dressing, sulphuric acid spraying. (Plant Pathology Department.) (3) Experiments on wheat, Little Hoos. Control of wireworm by soil fumigants. Residual effects of fumigation treatments applied to wheat in autumn 1947 (Insecticides Department).

EXHAUSTION LAND, HOOSFIELD

The exhaustion land consists of two acres in Hoosfield lying between the acre devoted to alternate wheat and fallow and the Long Hoos boundary. Since the early continuous experiments on potatoes were terminated in 1901 this land carried a series of corn crops, either unmanured or with nitrogen only. For many years the yields of grain and straw were measured on all the old potato plots, but this was allowed to lapse after the first world war. Nevertheless the cereals still showed small but quite noticeable residual effects in the spring associated with certain of the former treatments. These residues had attracted little attention in recent years, but in the very dry spring of 1949 the crop of barley showed such remarkable differences from plot to plot that a fresh examination of the site and crops was clearly necessary.

Soon after the barley germinated it was apparent that the young plants on those parts of the field where the former experimental potatoes had received either no manure or nitrogen only were in a miserable condition. They were stunted with dull greyish leaves carrying purplish markings, showing in fact all the symptoms of acute phosphate deficiency. The sites of the old dung plots and plots that had received a long series of superphosphate dressings for the potatoes carried normal plants. The effect was so striking that the Chemistry Department set on foot an intensive sampling of crops and soil. Air photographs taken on May 13th showed the differences in ground cover very clearly. A month later the worst leaf symptoms of phosphate deficiency had disappeared, but big differences in development and maturity remained. The old plots were cut

out and harvested separately, and chemical work on the grain and straw samples will shortly be put in hand. Arising out of the renewed interest in this piece of land it was thought desirable to put on record as much of its previous history as could be ascertained from old records.

The first mention of this area of the Rothamsted farm appears in 1856 in a paper by Lawes and Gilbert dealing with a system of growing wheat advocated by the Rev. S. Smith of Lois Weedon in Northamptonshire. The plan was to grow wheat year after year in the same field, the land being subdivided into alternate narrow strips of crop and fallow. The crop of one year stood on the fallow ground of the year before. The wheat was unmanured and deep cultivation was practised. This experiment began in 1851 and continued till 1855. From 1856-1874 this land carried a succession of wheat crops in a fertilizer experiment on four plots rather on the lines of Broadbalk. The annual treatments for wheat were: (1) complete minerals, (2) nitrogen and minerals, (3) nitrogen only, (4) no manure. The yield of these plots for the first 8 year period appear in the Journal of the Royal Agricultural Society of England, 1864, vol. 25, where they were compared with the corresponding yields of Broadbalk. The figures for the whole 19 years are in the Rothamsted archives.

In 1876 the fertilizer experiment on continuous potatoes began on the same plots and the treatments were so arranged that all four previous treatments for wheat were carried through into the potatoes on the same land. Additional treatments for potatoes were obtained by halving the original wheat plots.

The potato experiment continued until the crop of 1901 after which the land carried a series of cereal crops, usually barley, without manure of any kind. Yields were taken yearly till 1922, when cereal cropping continued without fertilizer but the crops were not weighed. Even at that period the residual effects of the dung and phosphate treatments in barley were still plainly visible, particularly in certain seasons. In 1940, it was decided to give generous basal dressings of sulphate of ammonia only, and since then the cereals have received about 3 cwt. nitrogenous fertilizer per acre yearly. It was in the presence of 2¼ cwt. of sulphate of ammonia that the barley of 1949 showed the remarkable residual effects previously described.

Irrigation of Sugar Beet

Two experiments were carried out in 1949, one on Mr. F. A. Secrett's farm at Milford, where experiments had been in progress for the previous two seasons, and the other on the land of Messrs. W. O. and P. O. Jolly at Kesgrave, near Ipswich. Both soils were light and free draining and both farmers practised overhead irrigation on commercial vegetable crops.

The summer was even drier than the very dry year 1947, and in great contrast to the wet summer of 1948 when irrigations had no effect. The following table shows the monthly rainfall at both centres during the summer months.

Summer Rainfall, inches

	Milford			Kesgrave
	1947	1948	1949	1949
May	1·67	2·06	2·21	1·99
June	2·14	2·60	0·45	0·42
July	1·06	0·96	0·73	0·72
August	0·52	4·02	0·96	1·54
Total	5·39	9·64	4·35	4·67

At Milford the experiment was a 6 × 6 Latin Square with the following treatments on the main plots:

1 and 2	No water (O)
3	Full irrigation as directed by farmer (F)
4	As 3, with Chilean potash nitrate in irrigation water (FS)
5	Restricted irrigation, based on weather data (R)
6	Restricted to a lower level, based on weather data (M)

All plots received a basal fertilizer dressing supplying 0·42 cwt. N, 0·68 cwt. P_2O_5, and 0·89 cwt. K_2O with 5½ cwt. salt per acre.

Within each main plot 4 levels of nitrochalk were tested:—

(a)	No extra nitrochalk	Total N 0·4 cwt. N
(b)	2 cwt. nitrochalk	„ „ 0·7 „ „
(c)	4 „ „	„ „ 1·0 „ „
(d)	6 „ „	„ „ 1·3 „ „

At Kesgrave the general arrangements were similar but the experiment was smaller and simpler; being 4 randomized blocks of 3 main plots, each split for three levels of nitrochalk.

Main plots:—1. No water (O)
2. Watering as directed by farmer (J)
3. Watering based on climatic data (M)

All plots received 0·43 cwt. N, 1·07 cwt. P_2O_5, 0·86 cwt. K_2O, and 3½ cwt. salt.

Sub-plots:—	(a)	No extra nitrochalk	Total N 0·4 cwt. N
	(b)	3 cwt. nitrochalk	„ „ 0·85 „ „
	(c)	6 „ „	„ „ 1·30 „ „

The crop at Milford was grown on narrow rows of 17 inches and closely singled, to give a very high plant population of 37,000. Unfortunately an extremely early and severe attack of virus yellows occurred. All plants were infected by the end of June and there is no doubt that the yield was seriously reduced. At Kesgrave a good commercial plant of 26,000 was secured. The virus yellows attack commenced about a month later than at Milford, and although the crop was damaged the effects were in no way exceptional.

The main results from both centres are set out in the following table:

Milford, 1949

Effect of Irrigation, dissolved nitrate, and fertilizer nitrogen

	Mean Yield	Irrigation, inches 0	6½	8½	13	S.E.	Increase for Nitrate	S.E.
Roots, tons ..	16·3	14·3[1]	17·5	17·8	16·9	0·42	0·1	0·59
Sugar % ..	12·2	12·02	12·3	12·5	12·3	0·13	—0·2	0·19
Sugar, cwt. ..	39·9	34·63	42·9	44·5	41·6	1·34	—0·6	1·89
Tops, tons ..	19·0	14·44	20·5	20·3	21·0	0·44	2·1	0·62
Plants, thous...	37·5	37·85	38·1	37·5	36·4	0·33	0·7	0·47
Noxious N ..	68·5	81·5[6]	63·3	59·6	59·2	3·30	7·0	4·60

[1] 0·30 [2] 0·09 [3] 0·94 [4] 0·31 [5] 0·23 [6] 2·3

	Fertilizer Nitrogen, cwt. per acre 0·4	0·7	1·0	1·3	S.E.
Roots, tons	16·8	16·3	16·6	15·6	0·22
Sugar %	12·4	12·3	12·1	12·0	0·064
Sugar, cwt	41·6	40·2	40·2	37·5	0·60
Tops, tons	18·0	18·7	19·2	20·0	0·27
Plants, thous.	37·9	37·7	37·4	36·8	0·23
Noxious N	63·1	64·4	72·8	73·9	1·72

Kesgrave, 1949

Effect of irrigation and Fertilizer Nitrogen

	Mean Yield	Irrigation, inches 0	4	5½	S.E.	Nitr'n., cwt. per acre 0·4	0·85	1·3	S.E.
Roots, tons	14·4	11·3	15·3	16·4	0·35	14·6	14·3	14·1	0·23
Sugar %	14·5	13·6	15·0	15·0	0·18	15·1	14·6	13·9	0·082
Sugar, cwt.	42·0	30·8	46·0	49·3	1·25	44·5	42·1	39·5	0·72
Tops, tons	10·2	9·5	9·7	11·3	0·29	9·3	10·4	10·8	0·25
Plants, thous.	26·6	26·9	26·5	26·4	0·34	27·7	27·3	24·8	0·33
Noxious N	69·6	78·3	65·9	64·5	3·6	59·6	70·9	78·2	1·8
Dirt Tare %	16·0	21·2	14·7	12·3		15·6	16·8	15·7	

The features of the Milford experiment were the very early and severe virus yellows attack and the exceptionally low sugar content of 12·0 per cent. The result was only a moderate yield of 34·6 cwt. of sugar on the dry plots in spite of a very high plant population. The lightest watering, 6½ inches in five applications, increased the output of sugar by 8·3 cwt. per acre, but there was no definite increase for the higher levels of watering. The heaviest watering, 13 inches in nine applications, gave a smaller yield of sugar per acre than 6½ or 8 inches, but not significantly so. Nitrogen in moderate dressings was ineffective and at the highest rate it significantly depressed the yield of sugar. There was no marked interaction between the effect of water and nitrogen. So far as the other attributes of the crop were concerned the sugar percentage was slightly but significantly raised by watering and depressed by nitrogen. Tops were increased by 6·1 tons by the lightest watering, with no further response for heavier applications, they were also slightly increased by nitrogen. Plant population was slightly reduced by the heaviest watering and by the highest nitrogen application. The figure for noxious nitrogen was greatly reduced

by watering, and markedly increased by nitrogen. The effect of adding Chilean potash nitrate, providing 0·4 cwt. N and 0·3 cwt. K_2O per acre, in the irrigation water was negligible so far as sugar was concerned, but it increased the tops by 2 tons and like fertiliser nitrogen it tended to raise the proportion of noxious nitrogen.

At Kesgrave with a crop of 30·8 cwt. of sugar on the dry plots, 4 inches of irrigation gave no less than 15·2 cwt. sugar per acre and there was a further increase for 5½ inches. Nitrogen reduced the quantity of sugar per acre significantly. These two factors showed a marked interaction, for the benefit from watering was much less when nitrogen was present, or alternatively the poor effect of nitrogen was most conspicuous on the watered plots.

Effect of 5½ inches water, no nitrogen	.. ..	23·4 cwt. sugar
Effect of 5½ inches water, with nitrogen	..	12·9 ,, ,,
Effect of 1·3 cwt. nitrogen, no water	.. ..	1·2 ,, ,,
Effect of 1·3 cwt. nitrogen, with 5½ inches water		—9·3 ,, ,,

At Kesgrave the effects on the other attributes of the crop were closely parallel to those observed at Milford. Watering increased the sugar percentage significantly, and nitrogen depressed it by 1·2 per cent. Both water and nitrogen increased the tops. Heavy nitrogen depressed the plant number. There was a decrease in noxious nitrogen due to watering, and an increase due to nitrogen. The roots on the dry plots were noticeably more hairy than the rest and picked up more soil at lifting time. The difference was clearly reflected in the figures for tare.

The main conclusions from the experiments of 1949 is that in a very dry year with an exceptionally hot dry summer, 6 inches of irrigation water was sufficient for a full crop, though it is possible that a disease-free crop might have used more. The interaction of nitrogen and watering will be further examined in future experiments.

Two Course Rotation

When agricultural salt was included from 1940 onwards as a treatment in the standard manurial experiments on sugar beet carried out in all Factory areas it soon became clear that 5 cwt. of salt per acre produced substantial increases in the yield of sugar over a wide range of conditions. The question then arose whether repeated applications of salt on the same land would continue to be effective for sugar beet. There was the further possibility, widely believed by farmers, that continued use of agricultural salt might damage the soil either structurally or in other ways. To test these points a long-period experiment was begun at Rothamsted in 1942. In order to break the sequence of sugar beet crops, a two-course rotation of sugar beet followed by barley was adopted, barley being chosen because it was the one cereal popularly supposed to benefit from salt dressings.

Two blocks of land were assigned to sugar beet and barley in Long Hoos field, the crops being changed over each year to give the two-course rotation. The following scheme of treatments was adopted. Four rates of salt application, 0, 2½, 5, and 7½ cwt. per acre, were used for the sugar beet. The salt was applied either before the winter ploughing or harrowed into the seedbed in spring

a few weeks before drilling the seed. On one set of plots these treatments were given to the sugar beet only, the following barley crop receiving no salt; on the remaining plots the barley also received salt treatments but at only half the rate given to sugar beet on the same plot. The sugar beet also tested muriate of potash at approximately 0, 2, 4 cwt. per acre, the muriate dressings being the equivalent of $1\frac{1}{4}$ and $2\frac{1}{2}$ cwt. of agricultural salt. All dressings were repeated according to the above scheme on their respective plots, hence at the heaviest rate certain plots received $7\frac{1}{2}$ cwt. of salt per acre to sugar beet followed next year by $3\frac{3}{4}$ cwt. per acre to barley. For the first two sugar beet crops in 1942 and 1943 and the first barley crop in 1943 the early application of salt was broadcast in the spring on land that had already been ploughed in the previous autumn. Subsequently for the six years 1944-49 inclusive, the early application of salt was always ploughed-in in winter for both crops.

The average results of the direct application of salt and muriate of potash to sugar beet taken over the 8-year period 1942-49 are given in Table I. The figures are the means of the two methods of applying salt on plots, half with salt to sugar beet only and half with salt repeated at half rate to barley.

Table I. Sugar Beet 1942-1949

Effect of Agricultural Salt and Muriate of Potash

Sugar: cwt. per acre

Salt to sugar beet cwt.	Muriate of potash 0	2 cwt.	4 cwt.	Mean
0	40·9	43·7	45·9	43·5
$2\frac{1}{2}$	50·0	47·8	49·0	48·9
5	50·0	50·2	49·5	49·9
$7\frac{1}{2}$	48·0	49·4	50·0	49·1
Mean	47·2	47·8	48·6	47·9

The level of cropping was very good. Agricultural salt in the absence of potash gave on the average the extraordinary increase of 9·1 cwt. sugar per acre for the $2\frac{1}{2}$ cwt. dressing. There was no indication of any benefit from heavier dressings of salt. In fact there was some suggestion that in the absence of potash $7\frac{1}{2}$ cwt. salt per acre was too much. Potash without salt also gave notable increases in the yield of sugar, but on a much smaller scale than the equivalent amount of salt. When salt was supplied there was no further increase due to potash, but salt still increased the crop substantially even when large amounts of potash were supplied. These results are in accord with those of the Factory Series of sugar beet fertiliser experiments in which on an average of 140 trials 5 cwt. of salt in the absence of potash gave 5·1 cwt. sugar, 2 cwt. of muriate of potash in the absence of salt gave 2·8 cwt. of sugar, and the two nutrients in combination gave 5·5 cwt. sugar.

The yearly increases due to salt in the absence of potash and to potash in the absence of salt are given in Table II for the eight crops of sugar beet grown in 1942-49.

Table II

Effect of salt (without potash) and of muriate of potash (without salt) in individual years 1942-49
1Na, 2Na, 3Na = 2½, 5, 7½ cwt. salt per acre to sugar beet, repeated at half rate to barley on half the plots
1K, 2K = 2, 4 cwt. muriate of potash per acre to sugar beet only
Sugar: cwt. per acre

	1942	1943	1944	1945	1946	1947	1948	1949	Mean
No Salt, No Potash	54·5	57·0	27·2	58·3	52·3	23·7	33·4	21·0	40·9
Increase for:—									
1Na	6·6	9·3	9·4	8·0	7·9	13·5	10·3	7·4	9·1
2Na	9·0	9·5	8·9	6·2	5·6	15·8	8·4	8·9	9·0
3Na	6·7	5·7	5·0	4·4	3·7	14·2	8·5	8·7	7·1
1K	−0·9	5·7	−0·1	4·5	−0·8	7·6	0·8	5·7	2·8
2K	2·8	6·3	4·4	3·2	6·9	7·4	2·3	6·6	5·0
SE+	2·63	3·07	2·47	2·15	2·71	3·54	3·12	1·36	—

The yearly responses to the first two rates of application of salt were large and very consistent. In every year except 1948 the highest dose of 7½ cwt. salt gave less sugar than the 5 cwt. application, and in 6 years 7½ cwt. salt gave less sugar than 2½ cwt. of salt, but none of these differences between rates of application of salt was significant in a single year. The comparatively poor effect of the heaviest dressing was most noticeable in the earlier years of the experiment; by 1947 the heavily treated plots were practically as good as the others. The data give no support to the idea that agricultural salt may lose its effectiveness for sugar beet if repeated at frequent intervals on the same land.

The effect of muriate of potash varied widely from year to year. In half the seasons the lower rate was ineffective, but in the others it gave an increase of about 6 cwt. of sugar per acre. The double rate gave better results even in the years when the single dose failed. As with salt there was no indication that the effect of potash fell off after many repetitions on the same plots. Indeed both nutrients at all rates gave bigger increases in the last four crops than the first four.

For the years 1944-49 there were no appreciable differences between salt ploughed-in in winter and salt broadcast on the seedbed in spring, and no effect from applying additional salt to the preceding crop of barley. Averaging all levels of salt, the figures were:

	Sugar: cwt. per acre
No Salt	38·7
Increase for:—	
Salt ploughed-in in winter	6·1
Salt broadcast on seedbed in spring	6·3
Salt applied to sugar beet only	6·1
Salt to sugar beet and at half rate to barley	6·3

Measurements of the effects of salt and potash were made on the other attributes of the crop and a condensed summary is given in Table III.

Table III

Effect of salt (mean of all rates of application) without potash, and potash (mean of all rates) without salt

	Roots tons	Tops tons	Sugar per cent.	Plant No. thous.
Mean yield, no salt, no potash	11·7	10·7	17·3	23·8
Increase for:—				
Salt, no potash	2·1	1·1	0·5	1·0
Potash, no salt	0·9	0·6	0·4	0·5

Salt had a markedly beneficial effect on all attributes, including plant number. Potash was about equal to salt in raising the sugar content, but only about half as effective on the remaining attributes. Examination of the yearly results shows that there was no reduction of plant number even in the presence of the highest dressings of salt and potash used together.

Effects on Barley. On the barley crop potash is always residual. Half the barley plots testing salt have salt applied directly at half rates and the remaining half tested only the residues from salt treatments given to the preceding sugar beet crop. The effects of these treatments averaging methods of applying salt are set out in Table IV.

Table IV. Barley: cwt. per acre, 1943-49

Effect of residual potash, and salt (direct and residual)

Salt cwt.	Muriate of potash cwt. 0	2	4	Mean
0	27·7	28·3	27·6	27·9
1¼	28·5	29·0	28·7	28·7
2½	27·6	27·9	27·3	27·6
3¾	27·1	29·0	28·4	28·2
Mean	27·7	28·6	28·0	28·1

Very satisfactory crops of barley were grown each year. On the average of the seven years neither residual potash nor salt had much effect on the yield of barley. The lightest dressing of each gave an average increase of only about 0·8 cwt. grain and there was no further increase for higher rates. In certain years, however, the effects were appreciable. In 1947 and 1949 the effects of residual potash were significant. In 1943 and 1945 there were significant improvements from salt, the direct effects of salt at half rate being greater than the residual effects of the full dressings. The mean effect on barley straw of residual potash and of salt directly applied was negligible.

Salt application produced visible effects on the physical state of the surface soil on this heavy loam when the land was in plough furrow. This was specially noticeable on the sugar beet areas on plots receiving the heavier applications in repeated dressings although it could also be observed on the barley land. The furrows on plots with much salt had a smooth slightly glazed appearance and were lighter in colour than those without salt. The effect was most noticeable after heavy rain. After harrowing the tilth on the heavily salted plots was noticeably more lumpy than the rest, but rolling produced a satisfactory seedbed everywhere and, as the figures show, the sugar beet plant population was not adversely affected. When lifting took place in wet weather the soil was more sticky on the heavily salted plots.

THE FARMS

By J. R. Moffatt

Rothamsted

During the year under review, no major changes of policy have taken place. Now that farming conditions are reasonably stable, the aim has been to secure sufficient staff, equipment, and materials to maintain a high standard of productivity both on the experimental field plots and on the non-experimental areas of the farm.

Field Experiments

Details of the field experiments are given in the report of the Field Plots Committee.

The number of experimental field plots, planned by the Field Plots Committee, increased from 1,412 in 1948 to 1,536 in 1949. The weather was helpful throughout the year in enabling the work on these plots to be kept up to schedule, but it had a detrimental effect on the yield of all root crops and grass plots. In the new and complex ley-arable experiment which started in the autumn of 1948 (and was described in the 1948 report) many difficulties were encountered, some of which had been anticipated. It was fortunate that only a third of the experiment was started during the year, and that the growth of grass on the plots to be grazed was severely limited by the drought. Modifications have been made in the experiment which should overcome most of the difficulties in the future. The direct re-seeded grass plots on the old grass field took well and a very satisfactory plant remains for the 1950 season. Similar plots on the old arable land had to compete with strongly-growing arable-land weeds, and were also much more affected by the drought, and the plant suffered in consequence. Spraying was done with 15 per cent. B.O.V. (sulphuric acid) to kill the Knot-grass (*Polygonum aviculare*), in which it succeeded, but some plots have had to be ploughed up ready for a fresh start in 1950, while others will need patching.

Cropping

The area farmed remained at 474¾ acres, of which 242 acres were under tillage crops and 102 under leys, giving a total arable area of 345 acres. The main crops were: wheat 72 acres, barley 69 acres, oats and dredge corn 17 acres, potatoes 31 acres, mangolds, sugar-beet and kale 25 acres, with smaller areas of linseed, rye, beans, peas, lucerne and vegetables. 5 acres, all under experiment, were fallowed. The main difference between the 1948 and 1949 cropping was the decrease in the area under wheat and a corresponding increase in that of barley, and an increase in the area under temporary ley. The area of permanent grass was reduced to 99 acres by the ploughing up of part of the area previously devoted to a grazing experiment, and it is hoped to reduce the permanent grass still further in 1950.

Spring Work

The winter corn was drilled by the middle of November, 1948, most of it under reasonable conditions, and the very mild weather enabled it to germinate rapidly.

The early months of 1949 continued generally mild and dry, and the excellent condition of the land made it possible to replough all the ground for roots, except the classical mangold field. The conditions also greatly favoured the early preparation of seedbeds for spring corn, which was all sown under excellent conditions. The continuation of the dry weather throughout March (with the exception of a light snow-fall early in the month), April, and early May enabled the seedbeds for the root crops to be thoroughly prepared, and all spring sowings were completed early in May. By the middle of the month, the dry weather and low night temperatures were retarding the growth of most crops, but the latter half of May brought much-needed rain which caused an almost immediate improvement in the appearance of all crops.

Summer Drought

The dry spell set in again in early June, when only 0·64 ins. of rain fell, and a long summer drought then developed. During the four months June-September inclusive, only 4·03 in. of rain fell, compared with the average of 9·68 in. The mean temperatures and hours of sunshine were well above average for each of these months.

The hot and dry conditions did not appear to affect the cereal crops, which looked very promising throughout the season, except on one field where the wheat plant was thin. Some of the wheat showed signs of coming into ear in mid-June, and all crops ripened earlier than usual. Several of the corn crops were treated with herbicides with very satisfactory results. One field of barley after a well-manured crop of potatoes became lodged fairly early, while thunderstorms about mid-July, although affording some relief from the drought, caused further lodging, although the damage was only severe in patches.

The hand-pulling of wild oats on Broadbalk wheat plots, carried out each year mainly by volunteer workers from the Laboratory staff, is effectively reducing the infestation of this weed. In 1949, section 5, which was fallowed in 1948, contained very few wild oats, but the area was hand-pulled thoroughly. Sections 1 and 2, after a year's fallow 3 and 2 years ago respectively, contained quite a few oats, but each was hand-pulled on two separate occasions, and if labour can be secured for this operation each year until they are next fallowed, the reduction in the wild oat population will be of prolonged benefit. Section 3, due to be fallowed in 1950, contained the heaviest infestation, but the plots in this section were cleared as far as possible, with the exception of plot 8, where there were too many weeds to be pulled by hand. The 1950 fallowing will considerably reduce the weed population of this section, after which the aim will be to prevent another building-up of weeds, by hand-pulling the area each year.

The linseed crop made good initial growth after fairly early sowing, but the drought then affected it badly and subsequent growth was very slow. There was also a very bad infestation of Fat Hen (*Chenopodium album*) in the crop, but this was very effectively controlled by spraying and dusting with MCPA herbicide. The

crop suffered slight initial distortion but soon recovered. The estimated yield of 5 cwt. per acre of seed is less than half the normal yield.

The experimental crops of peas and beans looked well throughout the season, except that the beans were severely attacked by bean aphis which, despite several sprayings with nicotine, considerably reduced the yield. A non-experimental area of beans which escaped early damage by birds was later so severely attacked that it had to be cross-drilled with a mixture of spring cereals. It was fortunate that this was done, as the beans which survived the bird damage were later so badly attacked by bean aphis that the harvested crop consisted almost entirely of cereals.

The dry weather retarded the growth of weeds in the root crops, but also the growth of the crops themselves. This enabled the regular farm staff to undertake the singling of the sugar-beet and mangold crops, which was completed towards the end of June. Fortunately the flea beetle was not so active as usual, and no precautionary dustings were needed on these crops. The kale crop, which was sown early, escaped with negligible damage, but a few later-sown areas were badly damaged. The root crops looked backward throughout the summer, very little growth being made, while the sugar-beet crop also had to contend with an early and severe attack of Virus Yellows disease.

Harvest Operations

The early ripening of the corn crops led to harvesting starting earlier than usual. Weather conditions were excellent throughout. Much of the corn which was cut by binders was carted direct from the binder rows without shocking, and was either stacked or threshed in the field. The grain from the areas cut by combine harvester was beautifully dry and free from weed seeds and green material. The wheat was sold without further cleaning, but because of the glutted state of the market the barley was held in store in the hope of better prices later. All harvesting operations were finished before the end of August and the threshing of outside corn stacks followed immediately. Yields of wheat and barley were both very good, and good yields are also anticipated from the oat crop.

Potatoes

The planting of the fairly large area of potatoes without additional labour was made possible by the use of a 2-row potato dropping attachment fitted to the hydraulically controlled toolbar of a tractor. This work was carried out in conjunction with the National Institute of Agricultural Engineering, and proved very speedy and efficient, for, as was shown by the experimental plots, the machine planting was superior to hand-planting. Besides the speed of planting, the dropper has the advantage over hand-planting that the tubers are planted direct into moist soil, whereas with hand-planting the tubers are often planted in ridges which have partially dried out. This factor is also likely to affect considerably the loss of plant if Dry Rot is present in the seed tubers. In a wetter year, it is possible that the difference in favour of the dropper would not be so marked, but the advantage is likely to remain with the dropper nevertheless. It has been the practice for several years to put

dung for the potatoes in the ridges just before planting, but manure added in this way would foul the openers of the machine. None was therefore used in 1949 on the areas planted by this machine. In future, dung will be ploughed-in during the winter months for the potato crop.

About half the potato area was planted with seed of Scottish "A" stock, the remainder being planted with the same variety but with seed grown at Rothamsted in 1948 for which an English "H" certificate was obtained.

The crop made reasonable growth during the first part of the season, but in July, August and September growth was very slow and ripening took place much earlier than usual. There was no sign of Late Blight during the season, so no precautionary sprayings were done. The haulm was burnt off with sulphuric acid before lifting began, to facilitate this operation. The lifting of the experimental areas started in mid-September, and was finished before the end of the month. This was followed by the lifting of the non-experimental crop, for which schoolchildren were employed. Yields were only about half the 1948 crop, and individual tubers were smaller than usual, with many damaged by cutworms. The crop has been stored under cover in the Dutch Barns to an average depth of 10 feet.

Grassland and Livestock

Haymaking started early in June, but the drought considerably reduced yields. The light crop was made under excellent conditions, however, and was stacked under the Dutch barns at the farmstead. In future most of the hay will be gathered by a pick-up baler, as not only will it be easier to handle and transport, but needing a smaller team of workers it will enable the singling of the root crops to be carried out without the interruption of haymaking.

The grass and clover seeds undersown in the cereal crops in 1949 took quite well and generally look quite promising for next season. On one area where the nurse crop of barley was badly lodged, however, a considerable amount of patching will have to be done. One area which was sown without a cover crop became badly infested with Fat Hen (*Chenopodium album*) and creeping thistle, but spraying with MCPA herbicide effectively controlled both these weeds and although the plant of grasses and clovers is rather thin, it will be left down.

The effect of the drought on the pasture land was very severe. The spring flush lasted only a very short time and by mid-July the fields were very parched. A second top-dressing of sulphate of ammonia was given to some fields, but as there was no rain to wash it in it had the unusual effect of burning up some of the clovers. Supplementary food had to be given to some of the stock from July onwards, and throughout July, August and September the grass fields presented much the same appearance as the stubble fields. Hay and straw had to be carted to the stock in September, and many of the cattle had to be sold before reaching the desired degree of finish. Many of the most forward of the cattle were brought into covered yards in October, to fatten them off as soon as possible, but several which should have fattened off the grass are now being over-wintered. 66 cattle were purchased during the winter of

1948/49, the majority of which were Irish steers. Some were out-wintered, but most were brought into covered yards to tread straw into farmyard manure. During the year ending 30th September, 1949, 71 fat cattle were sold to the Ministry of Food.

The number of Scottish Half-bred sheep in what originated as a Half-bred flock was further reduced during the season by culling, the replacements being home-bred ewe lambs out of the old ewes by Down rams. 140 ewes and some ewe lambs were put to Oxford and Suffolk rams to lamb early in April, but very few of the ewe lambs bore lambs and the lambing percentage was low. The flock has done reasonably well under difficult circumstances. The drought and consequent shortage of grass reduced the milk supply of the ewes, which affected the rate of growth of the lambs, very few of which were sold fat before the end of the year. They were folded on kale from early November, and have since improved considerably; and most will be sold early in 1950. 68 of the best ewe lambs and a few wether lambs have been retained for grazing experimental plots at Rothamsted and Woburn, and some of the ewe lambs may be brought into the ewe flock at the end of the grazing season.

Autumn Work

The very protracted drought lasted until the end of the first week in October, after which heavy rain was experienced for the rest of the month. October, normally the wettest month of the year with 3 in. of rainfall, was doubly so this year, producing over 6 in. of rain in the last three weeks, of which 2·67 fell on two days. More rain fell in this month than fell in the previous 5 months, and the land, much of which had been too hard for ploughing and too dry to work down to seedbeds, became far too wet to work. The preparation of the land for winter corn was thus considerably delayed, only a few experimental areas being sown by the end of October, 1949. However, a drying spell early in November enabled the drilling to be completed by the middle of the month, although on several occasions the conditions were not as favourable as could have been wished. The acreage of winter corn for the 1950 harvest has been considerably increased.

The delay in the start of drilling also delayed the harvesting of the sugar beet and mangolds. Mangold yields were well below average, while the sugar-beet crop was the most disappointing crop of the year. This was because of the combined effects of the drought and an almost hundred per cent. infection with Sugar Beet Yellows virus disease. Individual roots were small and the yield was considerably below normal. The sugar content too was disappointingly low, the average as returned by the factory being 14·7 per cent.

The weather in December, 1949 was much warmer and drier than usual, and this enabled the winter ploughing to be continued almost without interruption. Several fields have already been ploughed a second time, and an area of about 15 acres which has been under a long-term ley was ploughed before the end of the year.

Labour

The labour position this year was more satisfactory than for many years past. This was due primarily to the increase in the permanent staff made possible by the erection of the new cottages

for farm workers, but the weather played its part in that the growth of weeds was retarded and those that grew were easily destroyed in one operation. The amount of seasonal labour required during the year was therefore reduced to a minimum. The only occasions such labour was needed were for potato lifting and for sorting the last of the large 1948 crop of potatoes. The last sales were made by the Ministry of Food during late May and early June, by which time the regular staff were engaged in root singling. Fortunately the potatoes stored extremely well in the large heaps, and there was very little wastage even as late as June, 1949.

Machinery

Several additions to the list of implements were made during the year. A new tractor complete with many of its own range of specialized implements was purchased, and it is hoped that this will in future undertake many of the jobs on small plots previously undertaken by horses. A small single-wheeled motor hoe has been bought to facilitate the hoeing of small experimental areas where headlands are reduced to a minimum, and a new rotary hoe will keep clean the paths between the plots.

Buildings

Towards the end of 1949, a start was made with the erection of a new farm workshop and implement shed, to house the gradually increasing number of farm implements, many of which are at present housed in buildings designed and needed for other purposes. The building will be completed early in 1950.

Local Show Successes

Two horsemen and two tractor drivers took part in the local ploughing match, and between them won 2 first prizes, 3 second prizes, and a 3rd prize.

Conclusions

The execution of the year's work has been generally less difficult than usual. There was sufficient permanent staff to deal with most operations, which were therefore done on time, while dry weather extra equipment, and the use of herbicides enabled weeds to be kept under control. The weather also greatly facilitated the harvesting of the cereal crops, and enabled work to be kept up to schedule throughout the season. The results of the year's work, due to circumstances beyond our control, have been somewhat disappointing, for although the yields of cereals were satisfactory, those of all root crops, beans and linseed were low.

Woburn

The re-organization of the Woburn Farm, which commenced in 1947, when the management was merged with that of the Rothamsted Farm, was continued with satisfactory results. The main objectives of the year's work were to arrange the cropping so as to clean up, without resorting to bare fallowing, those fields not tackled in the previous two years, and to mechanize field operations where possible to enable the existing staff to tackle the increased arable acreage, and the anticipated higher crop yields, with the minimum expenditure on seasonal labour or outside contractors.

Cropping

The cleaning of several fields was tackled by intensive cultivation in preparation for, and during the growth of, a much increased area of potatoes, with a smaller area under sugar beet. The total area farmed was 127 acres, of which 52 acres were under cereal crops, 13 acres under various experimental crops or fallow, and the remaining 38 acres of arable land under potatoes or sugar beet; 24 acres were under grass. The area under experimental field crops was increased by the cropping, after a 2-year fallow, of the Permanent Wheat plots in Stackyard Field, although the actual number of plots was reduced to 422.

Mechanization

The partial mechanization of many of the operations proved very successful in that the work was completed within a short period and less seasonal labour was required. The most important of these operations was potato planting, which was carried out by 3 workers using a simple 2-row potato dropping attachment fitted to the toolbar of a tractor using a hydraulic lift. A second tractor was purchased during the year with a range of its own specialized equipment, and this not only undertook many of the operations previously performed by horses, but enabled both the experimental and non-experimental work to be kept up to schedule. Other smaller self-propelled machines have greatly facilitated the working of the experimental plots, while the replacing of out-of-date equipment by modern machinery has aided the execution of land work throughout the year.

The amount of seasonal labour required during the year showed a satisfactory decrease of approximately 30 per cent. over 1948, and it is hoped that in the years immediately ahead, seasonal labour will only be required for root singling, potato picking and threshing, and that for the latter will be provided from the Rothamsted staff during the winter months. Eventually it is hoped to mechanize both these operations.

Buildings

It was not possible to erect the new implement sheds, tractor garages, and covered barns which it was hoped would be erected during the year, but it is confidently expected that these buildings will be erected in 1950. The electrical circuits have been considerably extended, however, to provide adequate lighting and power points about the buildings, and it is hoped that the extended use of electricity now possible will reduce the amount of labour required around the farmstead.

Crops and Cultivations

The autumn corn was drilled during the first half of November, 1948, and although the soil conditions were far from ideal, about 30 acres of wheat and rye were sown. The winter remained favourable to farm work, the rainfall during the first three months of 1949 being well below normal, while there were few frosts, none of them very severe or prolonged. The mild weather encouraged the early germination of weed seedlings, which were destroyed by ploughing in, and on many areas three ploughings were given. Spring sowing operations began about mid-March and all crops were sown in good

time under favourable conditions. Early growth of all crops was slow, however, because of the dry weather and low night temperatures which occurred in the first half of May.

Fleabeetle damage, so prevalent in 1948, was almost negligible this year, except for an early attack on a small area of rape, which had to be resown, but periodic dusting with D.D.T. on susceptible crops was carried out as a precautionary measure.

The dry spring developed into a severe summer drought. In the four months June to September, 1949, the rainfall totalled only just over 4 in. compared with the average of 8·8 in., while the hours of sunshine and mean temperatures were well above normal. The effect of the drought was most severe on those experiments where the ground had to be prepared for the transplanting of cabbages and leeks. The cultivations were considerably delayed by the dry state of the soil, the plants had to be watered in on several occasions, and much patching was required to ensure a full plant. A severe aphis attack in late summer caused a further set-back to the cabbages.

The grass and clover seeds sown under the corn crops withstood the drought far better than in 1947, and all survived with a satisfactory plant. The grasses and clovers undersown in 1948 as experimental green manure crops made such rapid growth in the spring of 1949 that by the time the spring-sown rape and lupins were ready to be ploughed in the former crops were so heavy that they had to be cut and weighed off.

The dry spring and summer retarded the growth of pasture grass, and the spring flush did not last long. Subsequent growth was very slow, and the pastures were very bare for about 3 months, despite top-dressings of nitrogen. The fattening cattle were ready for sale during July and August, leaving only store beasts on the bare pastures. Hay yields were quite satisfactory for the dry season, and the crop was carted in good condition.

The weed problem was far less serious than in the past few years. The mild winter encouraged the early germination of many weeds, which were then destroyed, while the crops were sown under satisfactory conditions and were able to compete strongly with the later-germinating weeds. The dry weather prevented the weeds from growing very fast, and so enabled the motor and horse hoes to keep them under control. Herbicides were also used on cereal and pea crops. The fields have therefore presented a cleaner and tidier appearance than for several years past.

Corn looked very promising throughout the season, although some of the barley became lodged fairly early and other patches lodged after thunderstorms early in July. Wheat and oats stood well despite fairly heavy top-dressings of nitrogenous fertilizers. Harvesting operations started rather earlier than usual, and were continued almost without a hitch until they were finished almost exactly a month later. Much of the corn was not shocked, but was carted straight from the binder rows. The threshing of outside stacks of wheat and rye was done soon after harvest, and although the yields were rather lower than their appearance when growing suggested, the quality was excellent, and much of the rye was sold for seed. The barley, which was threshed later, was rather disappointing in both yield and quality.

The potatoes made reasonable growth in the early part of the season but growth was slow during August and September and the crop began to die off much earlier than usual. Because of the dry weather there was no incidence of Late Blight, and no spraying against this disease was therefore required. The harvesting of the experimental plots was completed in September, and yields were far higher than was anticipated, although the tubers were rather smaller than usual, with many affected by scab. The lifting of the large non-experimental area was completed in October, the haulm having been burnt off with acid to facilitate lifting operations. The yields here were much lower than average, and the tubers smaller, and there was also some damage by cutworms. The crop has been stored in an enclosed building at the farmstead to a depth of 10 ft. and will be sorted during the winter. The lifting operations were interrupted by the sudden break in the weather which took place at the end of the first week in October. During that month the rainfall was over 5 inches, almost twice the average.

Sugar beet proved the most disappointing crop of the season, despite the abundance of sunshine. The crop was affected very early with Sugar Beet Yellows virus, which spread throughout the whole crop. This disease, and the severe drought, resulted in low yields and a very disappointing sugar content. Harvesting was completed by the regular farm staff by the middle of December.

The rainfall during November, 1949, was slightly higher than average, but December only had half the average, and ploughing was carried out without much interference. 33 acres were sown with wheat and rye for the 1950 harvest, and early damage by game to these crops has been less than for several years past.

Livestock

Cattle

A small bunch of young cattle were over-wintered outside, mainly on sugar beet tops and oat or barley straw, and the mild weather enabled them to maintain their condition. A smaller number of stronger cattle were yarded during the winter to make F.Y.M. for experimental plots and were later sold fat off the grass.

Pigs

The small Large White pig herd has been maintained, most of the progeny being retained and carried on to bacon weight.

WOBURN EXPERIMENTAL STATION

By H. H. Mann

Season

The season of 1949 was as great a contrast with that of 1948, as it is almost possible to conceive, and the very dry summer months, especially June, July and September, made many of the usual operations in those months exceedingly difficult and sometimes impossible. All experiments which involved transplanting of crops during those months were affected, and in some cases, notably in the cabbages following green manuring crops, the results were consequently very different from what we have been accustomed to get in this experiment. The amount of grazing during the summer in the ley experiment was far less than usual, but, on the other hand, corn crops were at least up to the average and in the experiments where sugar beet or potatoes were grown, the reduction in yield, even on a light land farm like Woburn, was far less than might have been expected. The meteorological records from October 1948 to the end of 1949 are shown below.

Meteorological Records for 1948-1949

Month	Rainfall		Bright Sunshine	Temperature			
	Total fall	No. of rainy days		Maximum	Minimum	1 ft. in Grass minimum	
						ground	
1948	in.		hours	F	F	F	F
October	2·27	12	98·2	56·3	42·3	51·1	37·7
November	1·21	15	74·7	49·8	37·7	44·7	34·1
December	2·25	18	58·4	47·1	36·3	41·9	32·3
1949							
January	0·96	12	69·0	46·5	35·3	40·2	30·2
February	1·13	10	116·5	48·9	33·8	39·5	27·0
March	1·35	8	103·4	46·8	33·1	40·6	28·1
April	1·65	11	184·2	58·7	41·0	49·9	36·0
May	2·14	12	213·5	60·5	41·4	53·8	36·3
June	0·74	6	230·1	69·1	48·1	63·2	42·0
July	0·93	6	236·6	74·9	51·7	68·3	44·5
August	1·69	9	222·6	73·6	51·6	64·6	45·1
September	0·81	6	153·7	71·2	53·3	62·8	47·4
October	5·02	15	129·2	60·3	45·4	53·5	40·2
November	2·66	18	74·9	48·7	36·9	42·4	32·6
December	1·20	16	57·8	47·1	37·2	40·9	32·4
Total or Mean for 1949	20·28	129	1791·5	58·9	42·4	52·1	36·8

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that Committee will report separately on them. There are, however, a few points in connection with them that may be mentioned here.

In connection with the very serious infestation of wild oats on the permanent barley plots in Stackyard Field, records were maintained as to the number of plants which grew on this area, which, fortunately, was again kept fallow in 1949. On the worst portion of this area, the number of growing wild oat plants was counted on sample plots before most of the cultivations during the year. As noted last year, after a year of fallowing and intensive cultivation in February 1948, there were nearly 4½ million wild oat plants per acre and 3½ million a couple of months later. It is in the spring that most of the dormant wild oat plants germinate with

a subsidiary period of germination in the autumn. The gradual disappearance of the pest and the length of time it takes to get rid of it once the ground is badly infested is shown in the following series of figures.

	Number of wild oat plants per acre
May 1948	2,400,000
September 1948	1,200
November 1948	584
March 1949	32,625
May 1949	14,888
October 1949	4,400
January 1950	3,108

It is evident that one year's fallow leaves still enormous numbers of viable wild oat seeds in the soil: two year's fallow gets rid of most of these, but even after three years there are still quite a fair number of seeds still capable of growing. Two other interesting points emerge from our observations. First, practically all the wild oat plants spring from seeds in the top few inches of the soil: it is rare to find a living oat plant rising from below the plough level. Second, the greater number of autumn plants in 1949 over 1948 seems probably to be connected with the dry summer in 1949 which would lead to the greater likelihood of water penetrating the hard skin of the wild oat seed. On the whole, it is clear that even three years of intensive fallowing will not entirely eradicate wild oats when once they have really become a heavy infestation.

One of the matters which have for a number of years been a feature of the Woburn Station has been the growing of certain exotic crops, which seem to have possibilities in this country, especially on the well drained but semi-acid soil which is characteristic of the Station. For most of the crops which we have studied, 1949 has been a very good season, giving some of those more suited to warmer climates a greater chance of ripening than was the case, for example in 1948. The crops of this kind grown in 1949 have been hybrid maize from the United States, soya beans bred for long days in Sweden, serradella, and birdsfoot trefoil for forage.

With regard to maize, where we grew several of the early Wisconsin hybrids (seed of which was kindly supplied by Dr. Neal of that State), we were able to ripen all the types supplied and to get a crop much earlier than was the case in 1948. The yield was also much higher, and the ripening about 30 days earlier than in 1948. The yields obtained are shown below:—

Variety	*Note as to earliness*	*Yield of dry grain per acre*
Wisconsin 275	Very early: rather dwarf plants ..	2·20 tons
Wisconsin 240	Fairly early: taller than 275 ..	1·69 tons
Wisconsin 1600	Earliness as 240	1·03 tons
Wisconsin 255	Latest of the four varieties and the tallest	1·20 tons

The only manuring given was 3½ cwt. of sulphate of ammonia per acre on May 17th, the maize having been sown on April 21st. To get these yields it is necessary to obtain seed direct from the breeders: to test this point we grew Wisconsin 240 from our own seed of this

variety grown in 1948; this only gave a yield of 1·20 tons per acre as against 1·69 tons for the freshly imported seed. It seems that these early hybrid varieties of maize could have an important place in British agriculture, especially among small holders, very little seed being needed and the crop being used for feeding without threshing, after grinding the whole of the cob together.

With regard to soya beans, we have grown a number of varieties developed by Holmbergs of Sweden, as suited for higher latitudes than the soya bean areas of the U.S.A. and so ripening under our conditions when the usual American types will not do so. The usual difficulties with this crop in the past have been that the high yielding varieties would not ripen, and the types which could be relied on to give ripe beans were very poor yielding. The Swedish soya beans that we have grown in 1949 are dwarf types and can be grown much closer spaced than is usually the case, but even with our usual spacing we were able to reap $13\frac{1}{4}$ cwt. of dry beans of some of the varieties per acre. This certainly gives promise that when proper spacing is adopted we shall reach a commercial yield under British conditions.

Other exotic crops that have done well at Woburn in 1949 have been serradella and birdsfoot trefoil, both suitable crops on semi-acid soils for fodder growing. The latter, grown from American seed, gave just under three tons of green fodder per acre on July 7th from seed sown near the end of April, while it has continued to grow and appears likely to give at least the same amount of fodder in 1950.

Pot Experiments

Clover sickness

We have been working at the question of the failure of clover to give a remunerative yield when grown too frequently on the same land, for a number of years, even in the absence of any known pathogen, and we have ventured to bring our results before one of the scientific societies during the past year. The cause of the failure is still undetermined, but we seem to be approaching a solution and we can perhaps summarize the present position here. Tests made over a number of years made it clear that even in the absence of clover rot fungus and the well known stem eelworm, clover growth became less and less in successive years if any of the usual varieties were grown year after year on the same soil. After growing clover for about five years in this manner, the soil became so clover sick that only tiny plants could be produced, and no known pathogen has been found which would account for the reduction in size.

We investigated the question as to whether the production of the sick condition in the land could be speeded up by increasing the temperature at which the clover is grown, by growing the plants under semi-waterlogged conditions, and by other methods. The only striking result has, however, been obtained by increasing the proportion of growing clover to soil, i.e. by growing as much clover as could be crowded into a pot, on very shallow soil. Under these conditions the soil becomes sick very much more quickly and this suggests the possibility that the clover itself leaves something in the soil which is inimical to further growth of clover.

It quickly became evident that the addition of plant foods to the soil in the form of fertilizers would do little, if anything, to restore the healthy and proper growth of clover. This was found by Lawes and Gilbert nearly 100 years ago, and we can confirm their conclusions. They, however, state that if the soil contains large amounts of organic matter clover sickness does not appear nearly so soon as in other cases. Hence we tried the effect of addition of large amounts of farmyard manure to the sick soil and at once we obtained again a normal growth of clover. The effect did not last long, and on continuing to grow clover in succeeding years, the soil quickly reverted to the sick condition. Next we tried the effect of heating the soil in a moist condition to 70°C. for two hours, with the result that normal growth was again obtained though not quite up to the standard of fresh soil. This has been repeated several times, always with the same result. If the soil is heated in the dry condition, little effect is found. Other methods we have tried are (1) treatment of the soil with toluene to remove any active organisms. This gave no improvement of the clover on the sick soil, (2) treatment of the soil with formalin and then washing out the formalin with water. In this case slight but not very marked improvement was shown, but nothing like the growth on fresh soil was obtained; (3) the treatment of the soil with hydrogen peroxide so as to oxidize the more labile materials, and then washing out the reagent. In this case no improvement was reached. Negative results were also obtained when we tried to wash out any leachable materials from the soil, after which there was practically no improvement in clover growth, while the leachates applied to clover in healthy soil did little or nothing to bring about the dwarfing of the plants.

This is the stage at which the matter now rests. No definite pathogen has been identified which causes the condition here described, but its production can be intensified and quickened by increasing the proportion of clover to soil. The sick condition cannot be remedied by any addition of the ordinary plant foods to the soil, but can be temporarily got rid of by the addition of large amounts of farmyard manure or by heating the moist soil to 70°C. Washing the soil has no improving effect and the washings had no harmful effect on clover in fresh soil. Neither treating the soil with toluene nor partial oxidation with hydrogen peroxide did any good, while formalin had only a slight effect.

Competition of crop plants grown together

Starting as an investigation into the competitive power of several weeds with the barley crop, this work has been widened in the last two years into a study of the mutual effect of two crop plants usually grown together. In 1948 we studied the effect of barley and clover when grown together, and in 1949, the mutual effect of ryegrass and clover when laid down together, as is usual in an ordinary grass seed mixture. The results are now being worked up and promise to give results of distinct value. It is hoped to publish the results of the two years' work in the course of the next few months.

The nutrition of crops under very acid conditions

For a number of years an investigation has been in progress to find out why barley will not grow under conditions more acid than

that represented by a pH value of 4·7 to 5·0. The special points that have been worked at in 1949 have been the relative effect of acidity (pH value), presence and absence of soluble phosphates in the soil, and the question of whether the actual amount of calcium present has any effect on the growth of the barley. The plan of the experiment enabled us to separate clearly the effect due to the several factors mentioned, and we are now working up the results with a view to early publication. It is clear, however, that while the dominant factor in the failure of barley on the very acid soil is the presence of something which can be precipitated by soluble phosphates even if these do not cause any reduction in acidity, there is a clear effect of calcium salts which do not raise the pH value. A still more striking result was obtained with lucerne, which was made to grow on soil at a pH value of 4·2 after the addition of sodium phosphate in large quantities.

Laboratory Work

Changes in the sulphur content of soils under long treatment with artificial and other manures

At Woburn we have land which has been under barley for nearly eighty years being treated with various manures every year, and from these plots samples of the soil have been taken from time to time at least during the first fifty years. In some quarters the changes in fertility have been attributed in some measure to changes in the available sulphur content of the soils. This matter has now been under investigation for several years and the work is now drawing to a close. It is hoped to complete it during the next few months.

Most of the time of the laboratory staff is usually taken up with the analyses, etc. in connection with the field and pot experiments. Most of this work falls on Mr. Barnes and his staff, together with the detailed carrying on of the pot experimental work.

At the end of the year, Mr. Barnes has also taken over a good deal of the recording of the field experiments, and has also become resident on the Station itself.

SOIL SURVEY OF ENGLAND AND WALES

By A. Muir

The work of the survey has, in the main, been confined to those areas reported on last year. The general demand for soil maps and information on special areas continues.

Lancashire

Sheet 75 (*Preston*)

Detailed field survey in the Preston region was continued and about 13,000 acres were mapped on the 6″ to 1 mile scale. Surveying was largely concentrated in the south east, around Chorley—an area of Carboniferous sediments which vary from fine mudstone to very coarse sandstone. Though outcrops of the solid formations are common, particularly towards the rising ground in the east, most of this district is covered with glacial drift, whose great variations, both in colour and texture, reflect its diverse origins. Certain areas show a great confusion of glacial deposits due to the presence of overflow channels and morainic deposits, and it has been found necessary to delimit these as morainic complexs.

The soil series encountered include most of those noted in last year's report as occurring on the Carboniferous rocks or on glacial drift of Carboniferous origin, together with several tentatively named new series formed on glacial drift of mixed Triassic and Carboniferous origin. Two parent material types have been recognised; a sandy clay to sandy loam and a clay loam to silty clay. Variation in drainage gives rise to six series of which the Gillibrand, an imperfectly drained soil on the lighter drift, the Adlington, an imperfectly drained soil on the heavier drift, and the Coppull, an impeded soil on the heavier drift are the most commonly occurring in this district.

Brown Forest Soils occur in small patches and include two series not previously recorded ; the Chorley which has a sandy loam to loam surface over a loamy to coarse sand subsoil and is usually freely drained, and the Ellerbeck, a shallow, freely drained, very gravelly soil formed on coarse glacial flood gravel. Both these series are found in the areas of morainic deposits. Podzolic Soils are represented by two new series ; the Lever which is similar to the Rivington but shows incipient podzolization with iron pan developing about 2″ below the surface and the Anglezarke, a podzol developed on very coarse sandstone.

The soil pattern on the alluvial flats of the Ribble, to the east of Preston, is very complex, and is not readily mapped in detail, but two main groups of soils have been separated.

Somerset

Sheet 296 (*Glastonbury*)

Detailed survey on a scale of 6″ to 1 mile has been continued in central Somerset. An area of 29,000 acres extending south from Shepton Mallet to Castle Cary has been covered, so completing the field survey of O.S. Sheet 296.

The north-western portion of the area surveyed is relatively hilly, and associated topographically with the Mendip massif. Hereabouts, several small inliers of Carboniferous Limestone protrude through the dominant Triassic and Jurassic sediments. The Inferior Oolite, and the Upper and Middle Lias formations give rise to high ground near Castle Cary and the bold outlier of Pennard Hill. Elsewhere, the Lower Lias formation is dominant and the relief subdued.

Some thirty soil series have been distinguished, twenty two of which have already been noted. Of the new series, the Lulsgate, Wrington, and Ston Easton series belong to the Brown Forest Soil group and are leached soils developed on calcareous rocks of the Carboniferous, Keuper, and Lower Lias formations respectively. The Trip series is a gleyed calcareous soil derived from the Fullers' Earth Clay formation. Alluvium or colluvium mainly of Keuper origin give rise to the Birtsmorton and Tewkesbury series. The former is strongly gleyed nearly to the surface, with poor or very poor natural drainage, while the latter is gleyed in the subsoil only. Other series are of minor importance, and have been named only provisionally.

MONMOUTHSHIRE

Sheets 263 *and* 250 (*Cardiff and Chepstow*)

A reconnaissance survey of the Wentloog and Caldicot Levels bordering the Severn estuary was carried out at the request of the Ministry of Agriculture (Welsh Department). These levels have been largely reclaimed from tidal marsh within historical times, and are bounded by artificial "sea-walls." The predominant soil is the Wentloog series, belonging to the Gley group, and derived from estuarine silt-clay. Variation in the degree of drainage impedance as shown by soil morphology appeared to be correlated with the botanical composition and quality of permanent grassland.

WORCESTERSHIRE

Sheet 199 (*Worcester*)

A portion of the area in the south-east and east of this sheet had been previously surveyed. During the season some 14,000 acres were mapped on the 6" to 1 mile scale. The area covered consists of two blocks, the larger stretching from Kempsey northwards to Martin Hussingtree, the smaller area lies in the north-east near Dormston.

The geological beds around Worcester are mainly of red and green clays of the Keuper formation which are conformable with the Rhaetic strata to the east. A considerable part of the area is covered by glacial drift, while river terraces flank the Severn and extend two or three miles on either side. Strips of alluvium adjoin the Severn and many of the smaller streams. The area near Dormston is situated on the Rhaetic and Lias formations which consist of clays and fine-grained shales that in places are overlain by glacial deposits.

Nineteen series have been mapped of which fifteen had been previously distinguished, although some of these have been subdivided since they were first described.

The soils considered as Brown Forest Soils are derived from the sandy drift of the river terraces (Newport, Wick) and glacial deposits

overlying Keuper or Lias clay (Dunnington Heath, Newlands, and Pershore), while other Brown Forest Soils occur on recent alluvium (Wyre and Tewkesbury) and on the exposures of red and green Keuper marls (Worcester and Hurcot).

Non-calcareous gley soils, in which mottling appears at a depth of less than two feet, occupy considerable areas of the sheet and are found on Keuper clay (Spetchley), Lias clay (Charlton Bank) and on mixed Keuper and Lias alluvium (Fladbury). The Bushley series is found locally in wet spots on glacial deposits overlying Keuper Marl clay.

Four calcareous gley soil series were distinguished, two of which are as yet unnamed. Of the remaining two, the Evesham occurs on Lias clay and the Haselor on Lias clay with limestone bands.

Yorkshire

Sheet 71 (*Selby*)

The field mapping of this sheet was continued. Most of it is on the lacustrine deposits of the Vale of York, with a small area of solid Triassic, Jurassic and Cretaceous formations along its eastern edge, *i.e.* on the Western slopes of the Yorkshire Wolds. During the year mapping was restricted to the soils on the lacustrine deposits and the 21,000 acres mapped brings the total area now surveyed in detail to just over 60,000 acres. No new series were added to those previously described.

The lacustrine and more recent alluvial deposits give rise to a very flat topography with a high water table. This accounts for the great preponderance of gleyed soils, but a few examples of Brown Forest Soils and Podzolic Soils also occur.

The soils show very great textural variations. The lightest are those developed on patches of fine-grained sand covering the lacustrine clay, and locally they suffer considerably from wind erosion. The heaviest soils are those on the lacustrine clay and many of them are kept permanently under grass. The best agricultural land is found on the river sand associated with the Ouse and the Derwent, and in areas of loamy soils derived from mixed lacustrine deposits.

Sheet 70 (*Leeds*)

Two areas on this sheet had previously been surveyed by Dr. F. F. Kay as proposed sites for satellite towns. During part of the field season some additional mapping was done to unite these areas. The new area lies on Permian strata and the parent materials of the soils are Magnesian Limestone, Marl and boulder clay derived from both these formations with a varying amount of Millstone Grit material carried over from the west. In the 4,400 acres surveyed no new series were found.

Other Surveys

A reconnaissance survey of some areas of marginal land in the counties of Radnor, Brecknock and Montgomery has been carried out in connection with an investigation by the Statistics Department. A number of farms that have been taken over by the National Agricultural Advisory Service and other organizations for experimental purposes have also been surveyed.

REVIEW OF WORK ON NUTRITIONAL PROBLEMS IN FOREST NURSERIES

E. M. Crowther

Forest nurseries and forests offer excellent facilities for investigating soil fertility and crop nutrition problems. The levels of fertility in many nurseries and most forests are far below those common in farms, gardens and orchards. Nursery management is exhausting as the same crops, mainly conifers, are grown repeatedly, and both tops and roots are removed. Until recently little was added to the land beyond occasional dressings of leaf mould, farmyard manure or a variety of composts. Sometimes mustard or other green crops, receiving lime and ammonium sulphate, were dug in. Conifer seedlings grew very poorly in many of the older " established " nurseries, but there had been some spectacular successes with heavy dressings of carefully prepared composts in nurseries on heathlands or forest clearings. These results have been ascribed to an improvement in the mycorrhizal associations of the tree seedlings, and it has often been suggested that the effects of composts in relation to mycorrhiza might have important bearing on the nutrition of other kinds of crop and, thus, on general questions of soil fertility.

Opportunity to study these questions arose towards the end of 1944 when the Forestry Research Advisory Committee set up a Sub-Committee on Nutritional Problems in Forest Nurseries, under the Chairmanship of Professor F. T. Brooks, F.R.S.

Each year since then many experiments have been carried out in several nurseries and forests, mainly on Sitka spruce and Scots pine, in a most intimate collaboration between the Research Division of the Forestry Commission and several members of the Rothamsted Chemistry Department. When the broad lines of the programme have been approved by the Sub-Committee, Miss Benzian and Miss Roscoe are responsible for drawing up the detailed working plans, applying the treatments in all nurseries and forests in South and East England and in all forests in Wales, supervising the general conduct of the experiments and analysing the data. Mr. Warren, with Mr. Udall for part of the period, supervises the chemical analysis of soils, manures and crops and the preparation of special composts and manures. Mrs. Cooke undertakes pot experiments at Rothamsted. The Commission staff prepare the sites and do all cultural operations and assessments ; they also apply the experimental treatments in North England and in the seedbed experiments in West England and Wales.

For experiments continued only for a few seasons it has been found convenient to work with plots of one square yard. In this way it has been possible within a small area to test many factors in experiments of modern design. Sitka spruce, a particularly sensitive species, has been used throughout ; from 1945 to 1948 the plots in many nurseries were split to test Scots pine as well ; a few experiments have included many other species. The statements in this summary of results from nursery experiments are limited to mean heights of Sitka spruce. Seedbed experiments are assessed by height because this provides the only measurement which can be taken

conveniently on large numbers of plants which are to be tested subsequently in " extension experiments " in transplant lines and forests. The critical test of seedbed treatments lies in the subsequent establishment and growth of the plants. Many samples are also taken from seedbed plots for other measurements, such as diameter, dry weight, chemical analysis and root examination to see how far these provide better criteria than height for assessing the effects of treatments and for forecasting subsequent performance. In this summary the word " seedlings " refers to plants at the end of the first season (1 + 0) and " transplants " to plants after one season in seedbeds and one in transplant lines (1 + 1). In forestry practice Sitka spruce is generally planted out as 2 + 1, 1+2 , or 2 + 2 but a few successful trials with 1 + 0 seedlings had been made. The target put before the Sub-Committee was to find means of producing 1 + 1 transplants fit for planting and of avoiding such progressive deterioration of nurseries as had been so often experienced in the past. As the work proceeded increasing attention was given to planting one-year seedlings directly into the forests and to manuring them.

Composts

Dr. M. C. Rayner had suggested that composts acted through their effects on mycorrhizal and other fungi in the soil rather than by supplying nutrients directly to the seedlings. Thus, with Professor W. Neilson Jones (" Problems in Pine Nutrition," 1944, p.99), she had written " increase in the supply of available nutrients plays a relatively insignificant role in the maintenance of healthy and vigorous growth that follows addition of composts to the soil." Chemists were not unnaturally sceptical of this interpretation of the effects of materials rich in some of the major plant nutrients when used on soils singularly deficient in them. Dr. Rayner had supported her conclusion by the results of a critical pot culture experiment in which " soluble salts of nitrogen, potash and phosphoric acid corresponding to those in the composts evoked surprisingly little response in pine seedlings." (ibid, p.97). The evidence was, however, greatly weakened by the assumption that the amounts of available plant nutrients in composts could be estimated by growing oats in mixtures of compost and sand and interpreting their responses to additional fertilizers as in the Mitscherlich method for estimating fertilizer requirements of soils. There are good grounds for supposing that the composts would supply to the pine much more nitrogen, phosphorus and potassium than were provided in the small amounts of soluble salts assumed to correspond with the available nutrients in the composts.

In preliminary experiments in 1945 and 1946 at four nurseries several kinds of compost and farmyard manure were tested in factorial conbinations with fertilizers. At Sugar Hill Nursery, Wareham, Dorset, seedlings grown with fertilizers supplying nitrogen, phosphorus and potassium were much more vigorous than those receiving composts alone. The effects of contrasted kinds of compost were well related to their chemical compositions. Thus, hop waste compost was relatively rich in nitrogen and phosphorus but deficient in potassium, and seedlings receiving hop waste compost therefore responded particularly well to additional potassium as sulphate or chloride. Bracken compost was relatively deficient in phosphate but

well supplied with potassium. From 1947 onwards many special batches of experimental composts have been prepared and tested. A compost from bracken (preferably cut in early summer) and fresh hop waste has tentatively been adopted as the standard because it supplies moderate amounts of the three major plant nutrients, is easily prepared and has satisfactory physical properties. A good deal of attention has been given to preparing suitable composts from straw and to devising new kinds of compost intended primarily to protect added phosphates from too rapid inactivation by the soil.

In some nurseries the responses to compost or fertilizers were much smaller than at Wareham, especially where the soils were only moderately acid. At the responsive centres there were no consistent differences between the results from composts and those from fertilizers. In several experiments the plants with inorganic fertilizers were taller than those with composts, but in some other experiments, especially in dry seasons, the plants with compost were the taller. The combination of compost and fertilizers commonly gave larger plants than either kind of manure alone. It is to be expected that composts will improve the physical properties of the soil and liberate available nutrients more steadily and for longer periods than inorganic fertilizers. The use of fertilizers in forest nurseries is such a recent development that both in experiments and in practical trials there is a risk that unsuitable forms or amounts may sometimes be applied at inappropriate times. But difficulties also arise with composts and other bulky manures. The raw materials are often of indefinite and highly variable composition and the resulting composts may be deficient in essential plant nutrients. Sometimes they introduce weed seeds and excessive quantities of lime. They may also leave the seedbeds too open in dry seasons, as happened at several centres in 1949 when the compost plots carried fewer plants than the fertilizer plots. Raw bulky organic manures, *e.g.* fresh hop waste, dried bracken and chaffed straw have reduced plant numbers in most seasons.

Although the best results are to be expected from a judicious combination of organic manures and fertilizers, suitable raw materials are too scarce and the costs of transport and handling too high for manuring in forest nurseries to be limited to the use of composts. In forest nurseries, as in farms and gardens, the value of bulky organic manures and fertilizers should be assessed by direct experiment and interpreted mainly in terms of their effects on the chemical and physical properties on the soil and the nutrition of plant, until any clear evidence can be found to establish specific microbiological effects of benefit to the plants. So far, in experiments limited to tests over five years, no such evidence has been obtained from the subsequent behaviour of plants in transplant lines or forest plantings or from root examinations for mycorrhizal equipment made by Dr. Rayner and Dr. Levisohn. Many additional experiments are in progress to provide further evidence on these questions.

Fertilizers

When the present series of experiments was commenced it was believed that soluble fertilizers were dangerous when applied directly to seedbeds, transplants or newly planted trees. In many experiments excellent results have been obtained with ordinary agricul-

tural fertilizers, though the proper timing of nitrogen applications still presents difficult problems, especially in dry years and on weedy sites. Superphosphate has often proved markedly better than Bessemer basic slag, one of the few fertilizers previously tried in forest nurseries and forests. Very good results have also been obtained from a slowly acting nitrogen fertilizer, a plastic waste derived from formalized casein. In a large number of trials there have only been two instances of damage from fertilizer, both in 1948 on a very acid soil (pH around 4·0) at Wareham, Dorset. When superphosphate was used with late supplies of available nitrogen, either from organic forms in the seedbed or from late top-dressings of soluble salts, seedlings developed yellow needles. Transplants were scorched by top-dressings of ammonium sulphate but not by " Nitrochalk " or urea. There was no such damage at Wareham on lightly limed land in 1949 or at other nurseries in 1948 or 1949.

There was no evidence that seedlings provided with abundant supplies of nitrogen in the seedbed suffered in any way in transplant lines or in forest plantings. Indeed they often grew better than those with less nitrogen. During the droughts of 1947 and 1949 big seedlings were grown with inorganic nitrogen on watered plots. Transplants in 1948 brought out the interesting contrast that the extra height produced by additional nitrogen in the 1947 seedlings was maintained in the 1948 transplants but that due to watering was not.

In many experiments differences produced by seedbed treatments evened out when the weather was favourable for growth in the transplant year or after a couple of years in the forest. In some seasons of poor growth seedbed differences have been maintained or even increased, especially when the subsequent manuring was incomplete. It must be remembered that even moderate increases in mean height are often associated with large increases in the number of seedlings fit to transplant.

During the moist season of 1946 doubts were expressed whether the particularly large seedlings grown with fertilizers at Wareham would withstand the rigours of transplanting in distant nurseries. Batches of a thousand plants were distributed to several widely separated nurseries where they grew very well during the drought of 1947, beating the local stock.

Soil Reaction in Forest Nurseries

Many of the older nurseries of the Forestry Commission were established on agricultural land and in most of them Sitka spruce and other conifers now grow very poorly. The Research Nursery at Kennington, Oxford, is typical, though here the problem is not complicated by excessive weed growth as at several other nurseries especially during the war. Most of the older parts of the nursery has soil around the neutral point. Preliminary experiments in boxes at Rothamsted in 1945 showed that acidifying this soil greatly improved the growth of Sitka spruce. In several nurseries moderate improvements have since been effected by acidifying the soils with such materials as sulphuric acid, aluminium sulphate, sulphur and ammonium sulphate, but the general level of growth has not been raised to that obtained with suitable manuring on very acid soils. Residues from the acidifying agents often had harmful effects,

especially when dry summers followed. Experiments are in progress to test the effect of a year's fallow after acidifying the soils.

The possibility that poor growth at high pH values depends on some minor element deficiency has been repeatedly tested both by direct applications of salts to the plants or the soils and by growing agricultural and horticultural crops known to be particularly sensitive. No positive evidence of such a deficiency has been found, apart from repeated failures of yellow lupins, presumably from iron-deficiency, in one nursery on an isolated patch of highly calcareous soil on which conifers also failed. It is still quite uncertain whether the major defect in neutral soils is nutritional or microbiological.

The correlation between poor performance of conifer seedlings and high pH value of the soil was good enough to justify steps to prevent further liming of " established " nurseries or the unintentional introduction of basic material in seed covers, basic slag, composts and sewage sludge. The Forestry Commission has also decided to concentrate the bulk of its production of conifer seedlings in new nurseries on very acid heathland or forest clearings.

To provide information on the optimal pH range for tree seedlings and rotation crops, plots were established in 1947 at two nurseries with the widest range of pH values that could be obtained by steeply graded dressings of aluminium sulphate or calcium carbonate. In the first season many species of conifers grew poorly at high pH values and most of them grew well at pH values so low that possible rotation crops failed. As these plots settle down they may provide useful chemical and biological material for further investigations on the ways in which soil reaction affects tree seedlings.

If, as appears likely, conifer nurseries should be kept very acid to favour the seedlings and to restrict weeds, it will be difficult to devise suitable rotations with leys or green manure crops intended to maintain soil organic matter. A number of observation plots have been laid down on crops with low lime requirements, *e.g.* lupins, birdsfoot trefoil and various grasses. Rotation experiments have been started using, where necessary, the minimum amounts of limestone believed to be necessary to allow some choice of resting crops. Early results suggest that great caution must be exercised in applying agricultural cropping systems to forest nurseries. Sitka spruce in 1949 after white clover in 1948 was much inferior to that after a previous crop of Sitka spruce or a bare fallow. Some evidence has been obtained of a residual benefit from a grass ley.

Steam and formalin

Each year since 1945 Mr. J. A. B. Macdonald, Sylviculturist (North) of the Forestry Commission has obtained notable improvements in Sitka spruce seedlings on slightly acid or neutral soils by " partial sterilization " with steam or formalin, and similar results have been obtained in many experiments by the Rothamsted staff since 1946. Then in 1948 formalin (1 lb. commercial solution and 9 lb. water per square yard) applied a few weeks before sowing improved mean heights in 24 out of 26 experiments in nine nurseries. Steam and formalin given in the winter of 1947-48 improved growth in successive Sitka spruce crops in both 1948 and 1949. The benefits were sharply localized, the edges of treated plots and bands standing out clearly in continuously sown beds. Whatever the mechanism of

"partial sterilization" it is not easily annulled by reinfection from nearby untreated soil.

A special set of experiments was started in 1949 in an old nursery on neutral soil over Lower Greensand near Ampthill, Bedfordshire to allow microbiologists and chemists at Rothamsted and mycologists at Cambridge to make detailed studies of the changes occurring in treated soils. In one of these experiments the mean heights of Sitka spruce were increased from 1·1 inches on untreated soil to 2·1 inches with formalin and 2·5 inches with steam. Most of the plants on the treated plots but very few of those on the untreated plots were fit to transplant or to plant directly in forests. Steam and formalin also check weeds, especially in the critical early stages of growth. Although this would be of great practical value in large-scale applications, it complicates the interpretation of experimental results and serves to illustrate the way in which effects of "partial sterilization" depend on the balance and interactions between different kinds of organisms.

Hitherto, most investigations on such drastic soil treatments as steam and formalin have had to be restricted to greenhouse crops unsuited for adequately replicated factorial experiments. The possibility of applying modern laboratory methods to large numbers of small plots of a sensitive crop opens up many promising lines of investigation. When more is known about the mechanism of the effects it may become possible to devise cheaper methods fit for more extensive use in forest nurseries and, perhaps, in market gardens.

Forest experiments

In each season since 1947 batches of seedlings and transplants have been planted in three or four forests to test their performance. So far only the assessments for the 1947 plantings on acid heaths or moorlands have been fully analyzed. Establishment was good for both seedlings and transplants. On the average of all experiments plants raised with fertilizers were slightly taller than those raised with compost. A tentative general conclusion is that seedlings large enough for transplanting in the nursery may safely be planted in the forest, whatever their manurial treatments have been on the nurseries. If this finding is confirmed in further experiments and large-scale trials, it will point the way to great economies in nursery work.

The Forestry Commission rarely uses fertilizers in the forest, except on peaty soils in the West of Scotland, when newly planted trees may receive basic slag. In the present work striking results have been obtained in manurial experiments with seedlings and transplants on poor acid soils. Thus, on a Calluna site at Broxa in the North Yorkshire Moors there were very big responses to each of the elements nitrogen, phosphorus and potassium. On a grassy site on Dartmoor there were good responses to nitrogen and smaller ones to phosphorus and potassium. Some typical results from assessments late in 1949 on Sitka spruce transplants planted early in 1947 were:

	Broxa, Yorkshire		Dartmoor, Devon	
	Height inches	Diameter mm.	Height inches	Diameter mm.
Unmanured ..	14·6	10·3	26·4	13·4
NPK fertilizers ..	29·4	17·7	34·9	17·3

In several experiments manured seedlings (1 + 0) grew more vigorously than unmanured transplants (1 + 1), which after two seasons were already showing all the symptoms of " going into check." It is not yet known whether manuring will enable the young trees to withstand competition with aggressive Calluna, or whether on grassy sites the weeds may respond more rapidly than the young trees. Promising results have been obtained from slowly acting forms of nitrogen fertilizers. Soluble compound fertilizers have been used successfully by applying them on two sides of the tree, either in patches on the surface or in notches as granules or as compressed one-ounce pellets. Much more work will be needed to find fertilizers and methods of application likely to have sufficiently prolonged effects.

Pot Culture Experiments

A considerable amount of time has been devoted to developing a suitable pot culture technique for testing soils from many nurseries under comparable conditions and for examining more materials and combinations of treatments than can be tried in the nurseries. After a number of failures, suspected to have been partly due to " damping-off," success was attained in 1949 in experiments on the effects of steam, formalin and acid on soils from three nurseries in which conifers grow poorly. Additional tests were made on mixtures of treated and untreated soils to study re-infection. Acid, steam and formalin all reduced " damping-off " and improved growth. Early in the season the formalin treatments were outstanding but later the heights evened up considerably. The rough parallelism between control of " damping-off " and general early vigour of growth suggests that one important factor in " partial sterilization " may be the control of parasitic fungi.

Tops, Roots and Mycorrhiza

From the experimental plots it appears that in any one season and nursery the top-root ratio and the general form of the roots vary fairly regularly with the size of the plant. There are, however, large differences in root form between contrasted nurseries, some giving abundant fine fibrous roots and others pronounced tap roots or very large wiry laterals. It is not yet known which kind of plant is the best for various types of forest site. Until much more detailed work has been done on roots, it may suffice to judge the vigour of plants by the size of the tops or the thickness of the stem.

Good top growth and good root growth are not necessarily antagonistic. Although additional nitrogen may increase tops relative to roots, the larger reserves in plants with more meristems may help establishment and early growth after transplanting or planting-out in the forest. Acute nitrogen starvation is likely to set in only too rapidly in most forests, and it seems reasonable therefore to give the young plant the best possible start against its grim environment. The old view that plants intended for poor sites must be tough and wiry may be a relic from the times when nutritional conditions in nurseries were so poor or unbalanced that three or four years were required to allow the plant to pick up sufficient nutrients to withstand transfer to still poorer soils. The chemical view outlined above is not inconsistent with the theory that good mycorrhizal associations should be established as soon as

possible in the life of the tree. Whatever benefit the tree may ultimately derive from the fungus, the fungus must draw most of its carbohydrate from the plant. Even where additional nitrogen delays the plant's production of surplus carbohydrate for roots and fungus, this may be more than compensated for by the larger total amounts of surplus carbohydrate supplied later from the larger plants. The significance of mycorrhiza in young conifers is not sufficiently well understood for these matters to be settled deductively. The appeal must be to the actual behaviour in the forest of seedlings and transplants raised in adequate experiments.

The effects of compost in improving the growth of conifer seedlings in heathland soils were ascribed by the late Dr. Rayner to a stimulus from materials produced within the soil by mycorrhizal and other fungi. This hypothesis has the disadvantage that it can be developed only by difficult anatomical observations made by a few specialists working on quite small numbers of specimen plants. An alternative hypothesis, in much closer accord with the results of our experiments, is that the major plant nutrients in composts act directly on tree seedlings, and, through their better nutrition, encourage mycorrhizal associations in the roots. This interpretation has the advantage of simplicity and allows problems of soil fertility and nutrition in forest nurseries to be attacked by methods which have proved their value in agriculture and horticulture.

THE RELATION BETWEEN SOIL CULTIVATION AND CROP YIELDS

By E. W. Russell

Introduction

The Physics Department has been concerned with the effects of soil cultivation on crop yield ever since 1926. The results of the first eleven years' work were summarized in the Annual Report for 1936, and this report will carry the summary up to 1949. The work initially fell into two distinct sections : the effect of hoeing root crops on their yield, and the effect of different ways of preparing a seed bed on crop yield. Since 1936 two further sections of work have been added : the effect of earthing-up potatoes, and the effect of deep and very deep tillage on crop yields.

Summary

The great difference between this report and the one written in 1936 is that whereas in the former report practically no experimental cultivation treatment gave any appreciable increase of crop yield, some of those done subsequently have given consistent and occasionally quite large increases of yield. The reason for this difference reflects our greater knowledge on what cultivation treatments can and cannot do.

The original object of these cultivation experiments was to check the validity of some of the reasons commonly given by the farmer and farm adviser for carrying out certain cultivation operations, and the conclusion drawn from these experiments up to 1936 was that many of these reasons were in fact invalid. All subsequent work has reinforced the correctness of that conclusion.

The basis of much of the subsequent work has been to assess, independently of tradition but in the light of current scientific knowledge, the reasons why certain cultivations may be necessary, and to test the importance of these possible reasons in practice. By working this way round, it has been possible to pick out certain requirements that must always be met.

The first conclusion, which every experiment capable of showing has clearly shown, is that seedling weeds can have a very serious effect on the early development of the crop, and once the crop has suffered a check due to such a cause, it will usually never fully recover from it. One of the fundamental criteria that should be used in judging the necessity or value of a cultivation operation is, therefore, its effect on the weeds in the soil.

The second conclusion, entirely in agreement with that reached in the 1936 Report, is that the exact state of tilth of a seedbed is, comparatively speaking, of minor importance compared with some other factors. One of these other factors is the weediness of the seedbed, and another is its moisture content, but no further analysis of the factors has been made.

The third conclusion is that the principal effect of a moderate increase in the depth of ploughing is that it helps to control weeds in the seedbed but, in general, it has not affected the yields. But, if the depth of ploughing is doubled, from 6–7 inches to 12–14 inches, appreciable increases in yield of potatoes and sugar beet have been

obtained without the subsoil clay which has been brought up having any appreciable residual effect on the subsequent spring corn crop. The experiment has not yet been running long enough for any conclusions to be drawn on the effect of deep ploughing on the yield of winter wheat, as the results have been erratic.

This conclusion has not been fully substantiated in experiments made elsewhere in Great Britain, since one of the general conclusions of this series of experiments is that potato yields are very rarely affected by deep ploughing, although the yield of beet often is.

A fourth conclusion is that the best way of applying potash or phosphate to sugar beet is to broadcast them on the land before ploughing, and this is true whether the land is to be ploughed 6–7 inches or 12–14 inches deep. Again, this conclusion does not appear to be valid generally, but the conditions required for its validity have not yet been fully recognized.

(a) *The Effect of Hoeing Potatoes, Sugar Beet and Lettuce*

The experiments up to 1936 had been made to test if hoeing a soil, that is creating a loose dust mulch on the surface of a soil, reduced the loss of water by evaporation from the soil surface, so allowing more water to be available to the crop. Hence these hoeings were done in midsummer, between mid-June to mid-August, at which time one might expect the crop to benefit most from extra water, and the crops used were sugar beet and kale (1). These experiments showed that the crop yields were in fact either unaffected or were slightly reduced by additional hoeings during this period.

Potatoes. These results with sugar beet and kale were rather unexpected, so the experiments were extended to the potato crop, and were carried out from 1937 to 1939 by Dr. H. C. Pereira, under the guidance of Dr. B. A. Keen, the Head of the Physics Department at that time, on a light soil derived from the Bagshot Sands at Ottershaw Park, Surrey. The results of these experiments were published in 1941 (2).

Pereira's experiments fell into two parts. He examined both the effect of hoeing a bare soil, kept free from weeds, on its moisture content, and also the effect of hoeing between the rows of potatoes on their yield. In the first group of experiments he showed that the moisture content in the top 18–24 inches of soil, kept bare by using an arsenical weed-killer, was unaffected by hoeing the soil surface in each of the three years. Hence the loose soil mulch produced by hoeing could not increase the amount of water in the soil available to the plant.

In the second, and main group of experiments, the effect of frequency and depth of the hoeings and intertillage between the rows of potatoes was investigated. In 1937 some plots were not hoed at all, some were hoed twice and earthed up, some four times and earthed up, but the plots that were not hoed at all were kept free from weeds by hand weeding. The results of this experiment were that the plots hoed four times and then earthed up and the plots kept free from weeds by hand weeding and not earthed up gave almost identical yields of potatoes, namely 12·4 and 12·3 tons per acre, whilst those only cultivated twice before earthing up gave 10·4 tons per acre. These plots however were definitely weedier than those of the other two series. In 1938 and 1939 the experiments were design-

ed to extend these results. In each year plots kept free from weeds, either by hand weeding or using hoes or sweeps set to work no deeper than ½ inch, gave the same yields as plots receiving a number of hoeings, provided these hoeings kept the land free from weeds, and it did not much matter whether the hoes were set to work to a depth of 6 in., 3 in., or ½ in. But if any treatment was used that allowed even quite small weeds to develop in the crop the yield was invariably reduced. Thus the plots which were allowed to become a little weedy in 1938 had their yield reduced from 8·7 to 6·8 tons per acre, and in 1939 from 11·2 to 9·7 tons per acre.

Table 1 summarises the yields of potatoes under the various treatments, and gives in addition the per cent. ware in the crop, and it shows quite clearly that the sole benefit of hoeing to the potato crop was through its control of weeds.

Table 1. *The Effect of Weeds and Hoeings on the Yield and Per cent. Ware of Potatoes : Ottershaw Park.*

	Total Yield of Tubers in tons per acre				per cent. Ware			
	Clean Weeded			Weedy	Clean Weeded			Weedy
	not hoed	few hoeings	frequent hoeings		not hoed	few hoeings	frequent hoeings	
1937	12·3	—	12·4	10·4	91·8	—	89·8	88·1
1938	8·6	8·8	8·8	6·8	91·5	92·1	92·5	84·9
1939	11·8	11·0	10·7	9·7	90·6	90·5	90·7	89·7
Mean	10·9		10·6	9·0	91·3		91·0	87·6

Hence the conclusion drawn from these experiments, which were brought to a close by the outbreak of war, was that hoeing or cultivating the potato crop on the light soil at Ottershaw Park was only beneficial if weeds were killed : mere cultivations for the purpose of loosening the soil did not increase the yield in any of the experiments. Pereira also obtained some evidence to show that the cause of the harmful effect of the weeds was that they reduced the amount of water available to the crop. He further summarised the results of several hundred similar experiments that have been made with other crops all over the world (3), and showed that the general conclusion to be drawn from them was that the value of hoeing lay in its ability to kill weeds and not to make a surface mulch.

Two experiments were made at Rothamsted in 1942 and 1943 bearing on these results of Pereira's. These experiments contained the comparison of cultivating between the rows of potatoes two times and five times before earthing up, as well as comparisons of different fertiliser treatments. The results of these experiments are given in Table 2 :—

Table 2. *The Effect of Additional Inter-row Cultivations on the Yield of Potatoes*

Total produce in tons per acre : Rothamsted

	Two cultivations between rows	Five cultivations between rows	Reduction due to additional cultivations
1942	15·66	14·90	0·76
1943	8·38	8·14	0·24

In both years the additional cultivations, in so far as they had any effect, were slightly harmful.

Sugar Beet. These results of Pereira's received confirmation in a sugar beet experiment carried out at Woburn in 1939. This experiment was designed primarily for another purpose, but it contained a comparison between plots that were intensely hoed and those that received less hoeing. The intensively hoed plots gave a yield of 1·6 tons per acre of beet above the less intensively, and there was reason to suppose that this was largely due to an additional hoeing given shortly before singling. Another experiment with sugar beet at Woburn in 1940 again contained a comparison between two intensities of hoeings, and again the more intensively hoed plots outyielded the less intensively by 2·3 tons per acre when no nitrogen fertilizer was given the beet, but depressed the yield a little when 4 cwts. per acre of sulphate of ammonia were given, as is shown in Table 3 :—

Table 3 *The Effect of Nitrogen Manuring and Intensive Hoeing on the Yield of Beet at Woburn in* 1940

	Clean Beet in tons per acre		
	No Nitrogen fertilizer	4 cwts. per acre sulphate of Ammonia	Response to N.
Intensive Hoeing	18·8	14·7	4·1
Normal Hoeing	19·5	12·4	7·1
Benefit of Intensive	–0·7	2·3	

Once again there was evidence that the benefit of the intensive hoeing was due primarily to an additional hoeing given shortly after singling. Neither in 1939 nor in 1940 were the weeds obviously serious when this additional hoeing was given, and in 1940, but not in 1939, additional nitrogen fertilizer neutralised the harmful effect of the weeds.

In 1941 onwards, experiments were designed expressly for the purpose of checking points raised by these and by Pereira's results. In the first place it was necessary to prove that the sugar beet at Woburn was responding to the removal of the weeds and not to the mulch produced by the hoeing, and in the second to extend the work to other crops. The first point was established by comparing the effect of hoeing with hand weeding, and this comparison was made with sugar beet in 1941 and 1943. The results of these two experiments are given in Table 4 :—

TABLE 4 *Effect of Weeding by Hoeing or Hand Pulling on the Yield of Sugar Beet*

Yield of Clean Beet in tons per acre : Woburn

1941 *Experiment*

Sulphate of Ammonia Given	Period of Weedings		Before and after singling
	before Singling	after Singling	
None	9·7	8·4	10·7
Benefit due to hoeing compared with hand weeding			
	0·8	1·5	1·0
4 cwt. per acre	13·9	14·0	13·5
Benefit due to hoeing compared with hand weeding			
	0·4	–0·3	–0·3

1943 *Experiment*

Sulphate of Ammonia given	Weeding Programme		
	Minimum	Intensive weeding till 3 weeks after singling	Intensive weeding throughout season
None	6·3	8·7	9·6
2 cwt. per acre	8·9	12·2	11·8
4 cwt. per acre	12·9	13·4	14·0
Benefit due to hoeing compared with hand weeding			
	–0·7	0·1	–0·5

In both experiments, the yield of beet was not much affected by weeds if 4 cwts. per acre of sulphate of ammonia were used, but whilst this result was entirely accurate for 1941, it is possible that the beet

received some set-back from the weeds in 1943. In 1943 there was no benefit in hoeing compared with hand weeding, whilst in 1941 the hoed plots receiving no nitrogen yielded 1·1 tons per acre more than the hand weeded. It is probable that this benefit of hoeing is largely due to the better control of the small weed and twitch that it gave compared with the hand weeding.

The conclusion reached from these experiments is, therefore, that the yield of beet can be very appreciably reduced by quite small weeds up till 2–3 weeks after singling, that hoeing is an efficient means of killing these weeds, and that at Woburn the weeds reduce the yield of beet largely through the reduction in the amount of available nitrogen in the soil that they bring about.

Lettuce. Similar experiments to the sugar beet ones were made with lettuce at Woburn in the three years 1942–44. Lettuce was chosen as several market gardeners who were consulted considered that it was one of the vegetable crops most likely to benefit from the loosening of the soil surface brought about by hoeing. In the first two years, the experiment contained a comparison of frequent weeding with less frequent, weeding by hand with hoeing, and high and low level of fertilizers. In 1944 the experiment was modified a little in that the comparison was between clean weeding throughout the growing season and clean weeding while the crop was young.

The relevant results of these experiments are given in Table 5 :—

TABLE 5 *Effect of Weeding and Hoeing on the Growth of Lettuce : Woburn*

	Mean Yield	Increase due to frequent weeding	Increase due to hoeing compared with hand pulling
	Yields of Lettuce harvested in tons per acre		
1942	7·3	1·7	–0·7
1943	11·3	2·0	0·9
1944	11·8	4·9	0·9
	Numbers of Lettuce harvested in thousands per acre		
1942	26·7	1·9	–0·5
1943	53·1	–1·0	0·7
1944	41·9	11·3	2·1
	Weight per Lettuce in ounces		
1942	9·9	1·6	–0·8
1943	7·6	1·6	0·7
1944	10·1	1·5	0·2

The table shows that frequent, or continued, weeding gave larger lettuces than light or early weeding, though the outer leaves of the clean weeded lettuces were sometimes rather blanched. But

it made little difference to the crop if the weeding was done by hand or by hoeing, showing that it is the weed-killing action of the hoe, rather than the loosening of the soil which it causes, that is so important. Further, the harmful effect of the weeds on the lettuce could not be reduced by adding either an inorganic nitrogen fertiliser.

Conclusion. The three sets of experiments, with potatoes, sugar beet and lettuce, all show that weeds can set back crop growth very severely, and that an extra hoeing, by killing quite small weeds, can sometimes give a striking increase in crop. The main effect of the weeds seemed to be that they reduced the water supply to the potatoes and the nitrogen supply to the beet, and in particular for beet at Woburn quite a severe weed infestation sometimes had little effect on the yield if an adequate dressing of nitrogen was given.

In none of the experiments was there clear evidence that hoeing had any benefit apart from its weed-killing action.

(b) *The effect of earthing-up potatoes on their yield*

In the experiments of Dr. Pereira at Ottershaw Park, the potatoes on the unhoed plots were not earthed up, and, as is shown in Table 1, this lack of earthing up has not affected the yield of potatoes in any way. Nor did it affect the percentage of greened tubers appreciably. Hence there appeared to be no justification for earthing up potatoes on this light sandy soil from the point of view of obtaining a higher yield of saleable ware potatoes.

This aspect of Pereira's work received further investigation on the heavier soil at Rothamsted from 1946 to 1948. In 1946 and 1947 the effect of omitting earthing up of potatoes was studied when the inter-row cultivation given to the potatoes was done with tractor hoes set fairly deep and with them set shallow, and at the same time an additional treatment—applying a chaffed straw mulch between the rows of potatoes that received little cultivation and no earthing up—was put in. In 1948 it was intended to compare the effect of frequent with infrequent inter-tillage with and without earthing up, but the potatoes grew so quickly that all the plots received about the same number of inter-row cultivations.

The yield of potatoes, the per cent. ware and the per cent. of greened potatoes in the ware were estimated. In 1946, any potato having a spot of green on was classed as greened, in 1947 two categories of greening were used, that severe enough to prevent the potato being classed as saleable ware and that which was only visible to careful inspection, and in 1948 only one category was used, namely that which would prevent the potato being classed as saleable ware.

These experiments have thus only partially confirmed Pereira's results. In 1947 and 1948 earthing up put up the yield of saleable ware by about 12-16 cwts. per acre, whilst in 1946 it had a much larger effect if shallow intertillage was used but a smaller effect if deep intertillage was used. It is interesting to note that the straw mulch always gave a good yield of potatoes and its yield of saleable ware was about the same as the plots that were not earthed up in 1946, about the same as those earthed up in 1947 and was definitely the highest of all the treatments in 1948.

The results of these experiments are given in Table 6:—

Table 6. *Effect of inter-row cultivations and earthing up on the yield of potatoes: Rothamsted*

Hoes set	Earthed up		Not earthed up		Not earthed up
	Deep	Shallow	Deep	Shallow	Straw Mulch
	Total Tubers: tons per acre				
1946	12·40	12·96	12·44	11·66	12·68
1947	8·43	8·63	7·86	8·73	8·53
1948	12·74		12·92		14·63
	Ungreened Saleable Ware: tons per acre				
1946(1)	8·06	9·01	7·75	5·65	7·40
1947	7·14	7·68	6·35	7·02	7·25
1948	12·03		11·46		13·51

1 Total ware without any green

Summary: Beneficial effect of earthing up on yield of saleable ware in tons/acre

	Deep intertillage	Shallow intertillage	Mean
1946	0·31	3·36	1·83
1947	0·79	0·66	0·71
1948	0·57		0·57

The effect of the depth of intertillage was small, but there was a tendency for the shallower depth to be preferable if the potatoes were earthed up.

Conclusion. The effect of earthing up on the total yield of potatoes, whether on a sandy or a heavy loam soil has always been small, but it decreases the weight of greened potatoes at Rothamsted. This decrease was about 15 cwts. per acre in two of the years, and considerably more in the third, though a much more severe criterion of greening was used in this year than in the other two.

(c) *The effect of the tilth of the seedbed on crop yield*

A number of the Rothamsted cultivation experiments have given the rather unexpected result that quite large differences in the tilth of the seedbed, although they might visibly affect the early growth of the crop, did not usually affect the yields. No recent experiments have been made specifically on this point, but a mass of relevant information came to hand as a result of the Rothamsted Malting Barley Conferences which used to be held annually up to 1938. For a number of years growers of malting barley used to send in their samples which were then valued by a panel of valuers appointed by the Institute of Brewing. At the same time each grower filled in a questionnaire in which he gave the yield of barley and answered number of questions about the way he had managed the land, and in

particular he answered a question about the condition of the seedbed. The springs of 1936 and 1937 were both rather wet and farmers had considerable difficulty in getting suitable seedbeds on the loam and clay soils in these years. These two years thus afford a valuable test of how far the yield and the quality of malting barley is affected by the farmers own estimate of the suitability of the seedbed for this crop.

The results of this examination for the medium textured soils are given in Table 7:—

Table 7 Quality and Yield of Malting Barley as affected by the Condition of the Seedbed

Farmers' samples from medium textured soils

1936

Sowing date	Good Seed-beds		Poor Seed-beds	
	Valuations Sh./Qu.	Yield Bu./acre	Valuations Sh/Qu.	Yield Bu./acre
Before March 18	40/6	(33) 43	40/6	(6) 43
March 18-26	39/6	(32) 39	40/6	(10) 44½
After March 26	39/–	(16) 41	37/–	(16) 43

(The numbers in brackets are the number of fields involved)

1937

Sowing date	Good Seed-beds		Pair Seed-beds		Bad Seed-beds	
	Valuation Sh./Qu.	Yield Bu./acre	Valuation Sh./Qu.	Yield Bu./acre	Valuation Sh./Qu.	Yield Bu./acre
Before April 1	57/6 (7)	34	55/6 (17)	37	57/– (4)	37
April 1-19	54/6 (10)	33	54/– (18)	35	55/6 (7)	28
After April 19	51/6 (13)	37	55/– (5)	30	52/6 (8)	34

(The numbers in brackets are the number of fields involved)

This table shows the surprising result, that taken over the fields available, both the yield and the quality of the malting barley was independent of the suitability of the seedbed for malting barley as judged by the farmer himself. And this point was noticed with surprise by many farmers when they were completing the questionnaire.

(d) *The Rothamsted cultivation experiment: Long Hoos*, 1933-39

The results for the first three years of this experiment were given in the 1936 Report, and the results for the six years the experiment ran have been published (6).

This experiment had two main objects: first to find out if the land benefited by being cultivated to a depth of 7-8 inches instead of 3-4 inches, and second to compare the plough, the tractor cultivator or grubber, and the rotary cultivator as implements for breaking up the old stubble and for loosening the soil preparatory to the preparation of the seedbed. The experiment had three courses—wheat, mangolds, barley—and each crop was taken each year.

In the first place, for the whole of the six years, the yields on the plots ploughed to 3-4 inches every year were almost identical with those ploughed to 7-8 inches, and the few examples when the deeper ploughing appeared to benefit the crop were all on plots that had become rather infested with weed. The average results for the 6 years are given in Table 8:—

Table 8. *The effect of depth of ploughing on crop yields* (1933-39)

	wheat grain cwt./acre	barley grain cwt./acre	mangolds, roots tons/acre
4 in. ploughing	22·8	24·6	23·8
8 in. ploughing	22·7	23·7	24·5
benefit of deep ploughing ..	—0·1	—0·9	0·7
standard error of difference ..	0·4	0·4	0·4

In the second place it was soon found to be impossible to grow mangolds on land that had not been ploughed, because so much weed germinated with the mangolds that the crop was almost smothered. Hence the experiment had to be modified in its third year to allow the whole of the wheat stubble to be shallow ploughed after harvest. Further, neither the cultivator nor rotary cultivator used could go down to the full depth the first time over, so that they had to go over the land twice on the plots receiving deep tillage. This allowed them a better chance to clean the land, and possibly for this reason, deep tillage with these implements almost always gave higher yields and cleaner crops than shallow tillage, as is shown in Table 9:—

Table 9. *Increase in yield due to deeper and double tillage:* 1933-39.

	Wheat grain cwt./acre	Barley grain cwt./acre	Mangold roots tons/acre
Rotary cultivator	1·0	1·7	1·3
Tractor grubber	1·0	0·8	0·8

The general result of the six years' experiments was that land worked with the rotary cultivator or tractor grubber once and shallow always gave lower yields than the ploughed land, whilst land worked deep and twice always gave lower yields if the cultivator was used, and gave lower yields with wheat and mangolds but usually higher yields with barley if the rotary cultivator was used, as is shown in Table 10:—

There is an interesting conclusion to be drawn from the winter wheat results. The very loose deep seedbed prepared in the autumn by running the rotary cultivator over the land twice gives a better crop than the not so loose but more shallow seedbed prepared by running over the land once, as shown in Table 9, and although it

Table 10. *Reduction of yield due to using a cultivator instead of a plough* 1933-1939

	Wheat grain cwt./acre	Barley grain cwt./acre	Mangold roots tons/acre
Cultivator deep	3·5	1·2	1·9
shallow	4·5	2·0	2·7
Rotary Cultivator deep	3·5	—0·4	1·3
shallow	4·5	1·3	2·6

gave a reduction of $3\frac{1}{2}$ cwts. per acre compared with the plots that were ploughed, when averaged over the 6 years of the experiment, yet the reduction only averaged 2 cwts. per acre in the first two years when the land was still fairly clean.

Two conclusions were drawn from this experiment. Firstly the principal benefit of the plough compared with the rotary cultivator or grubber is the cleaner seedbed which it gives. Secondly freedom from weeds when the crop is germinating is more important than the exact state of the seedbed tilth. This last conclusion is entirely in accord with the results of all the other experiments so far discussed. Two other minor conclusions emerge. Barley seems to respond to the finer seedbed prepared by the rotary cultivator, provided there are not too many weeds present, and winter wheat is not unduly affected by being sown in the deep loose seedbed prepared by going over the land twice with a rotary cultivator.

(e) *The Rothamsted deep ploughing experiment: Long Hoos* 1944

This is a six course rotation experiment designed to test the effect of extra deep ploughing, to about 12-14 inches deep, with normal ploughing to a depth of about 6 inches. The rotation used is wheat—potatoes—spring oats—sugar beet—barley—seeds, and half of the plots are deep ploughed for wheat, potatoes and sugar beet. At the same time the response of potatoes and of sugar beet is determined to 20 and to 10 tons per acre respectively of farmyard manure applied just before ploughing, and also to a dressing of phosphate and potash applied either before ploughing or else in the seedbed for sugar beet and in the bouts for potatoes. These dressings have been 0·8 cwts. per acre of P_2O_5 as superphosphate and 1·0 cwts. of K_2O as muriate of potash for the potatoes and 0·6 cwts. per acre of each for the sugar beet. In 1944 only the potatoes and sugar beet courses were taken, in 1945 these and spring oats and barley, and in 1946 all the courses were running, although the wheat crop was on land deep ploughed for the first time that had received no manurial treatments. In the autumn of 1943 a somewhat unsuitable deep plough was used with the consequence that the quality of the work was poor and a depth of 12 inches was not maintained. In the autumn of 1946, owing to very heavy rains, the plots coming into wheat could not be deep ploughed. Otherwise the experiment has run as planned.

The soil on the site is mainly a fairly heavy clay loam, but at one side there is an area of a deep brick earth and elsewhere there are patches where a very tough subsoil clay comes near to the surface, and it has usually taken two deep ploughings to achieve the full 12-14 in. depth on the toughest of these patches.

Potatoes: 6 *years* 1944-49

The yield has been good in four out of the six years, but the yields were low in 1947 and 1949, both years of very dry summers. The yield of ware potatoes, in tons per acre, together with certain treatment responses, for each of the six years is given in Table 11.

Table 11. *Yields and Responses of Potatoes:* 1944-49
Ware in tons per acre

Year	1944	1945	1946	1947	1948	1949	Mean
Yield	10·6	10·3	10·9	5·6	14·7	5·7	9·8
Response to farmyard manure, when ploughing is							
Deep	1·45	3·01	1·91	1·67	4·24	2·00	2·38
Shallow	1·09	3·57	1·01	1·61	5·04	2·72	2·50
Response to deep ploughing when potash is applied in the bouts	0·47	1·75	0·78	0·73	2·93	0·88	1·26

Farmyard manure has increased the yield of potatoes in each of the six years, giving an average increase of 2·4 tons per acre of ware, though the annual response has varied from 1 to 5 tons per acre. Table 11 also shows that the increase in yield has been, on the average, the same for the deep as for the shallow ploughed plots, even though much of the dung must have been buried between 6-12 inches deep on the deep ploughed, and all was in the top 6 inches on the shallow ploughed plots.

The effect of deep ploughing on the yield of potatoes has been very dependent on the way the potash in particular, and to a much lesser extent the phosphate, has been applied, as is shown in Table 12:—

Table 12. *Effect of Depth of Ploughing on Yield of Potatoes*
Ware in tons per acre (1944-49)

Depth of ploughing	Potash given			Phosphate given		
	none	ploughed in	in bouts	none	ploughed in	in bouts
12 in.	9·26	10·30	11·55	9·96	9·70	10·77
6 in.	9·28	9·75	10·29	9·26	9·83	10·25
Response to deep ploughing	−0·02	0·55	1·26	0·70	−0·13	0·52

This table brings out clearly the way potatoes have responded to deep ploughing if potash is given in the bouts, and, as shown in Table 11, this result has been found every year, though its effect was small in the first year, 1944, when the full depth of ploughing was not reached. Also the average response of potatoes to potash has been higher on the deep than on the shallow ploughed land. It is possible to analyse these responses in more detail by separating out the yields on the plots receiving farmyard manure from those

that do not. This analysis shows that for the 6 years under discussion, the potatoes did not respond to potash where the farmyard manure was given, unless the land was both deep ploughed and the potash was put in the bouts. These plots gave an average yield of 12·57 tons per acre, being one ton per acre larger than the highest yield given in Table 12. In the absence of the farmyard manure, potash increased the yield of potatoes on the deep ploughed plots by 1·9 tons per acre when it was ploughed in and by 2·8 tons per acre when it was put in the bouts, and on the shallow ploughed plots the increases were 0·7 and 1·8 tons per acre respectively. Deep ploughing, therefore, has not enabled the potatoes to make better use of the farmyard manure, but it has enabled them to make better use of potash. There is no marked effect of phosphates on the response of potatoes to deep ploughing, but there is an indication that deep ploughing is most effective when farmyard manure is given and phosphates are then spread in the bouts. The general conclusion thus seems to be that the more favourable the manurial conditions are for potatoes, the more benefit they are likely to receive from deep ploughing.

Sugar beet: 6 years 1944-49

The yield of beet has varied from 9 to 15 tons of washed beet per acre, averaging 12·85 tons over the 6 years. The average responses over this period are given in Table 13:—

Table 13. *Average Responses of Sugar Beet to Deep Ploughing and Fertiliser Treatments* (1944-49)

	Mean Yield	Response to			
		deep ploughing	farmyard manure	potash	phosphate
beet, tons/acre	12·85	0·75	1·26	0·41	0·19
tops, tons/acre	13·94	0·99	1·40	0·62	0·03
sugar, cwt./acre	43·7	2·8	4·4	1·8	0·8
sugar, per cent.	15·32	0·00	−0·12	0·19	0·03
plant number thousands/acre	23·6	0·4	0·3	0·3	0·1

The six annual values for the yield of total sugar, and for the responses of beet, measured by the amount of sugar produced, to certain of the treatments are given in Table 14:—

Table 14. *Yield and Responses of Sugar Beet in each Year*
Total sugar in cwt. per acre

Year	1944	1945	1946	1947	1948	1949	Mean
Yield	34·1	58·0	50·5	40·7	52·9	26·0	43·7
Response to							
deep ploughing	1·4	3·2	2·5	12·4	−4·5	1·6	2·8
Farmyard manure	2·6	3·4	1·8	9·0	2·6	6·8	4·4
Fertilisers ploughed in							
phosphate	2·9	2·6	2·8	0·3	1·9	−0·8	1·6
potash	5·0	2·0	3·0	3·0	4·6	−0·1	2·9
Fertilisers put in seed-bed							
phosphate	1·1	0·4	2·2	−0·1	−2·6	−1·0	0·0
potash	2·8	1·8	3·6	−0·1	−3·4	−0·2	0·7

The yield of sugar is seen to be very satisfactory in four of the years, but to be rather low in the first year of the experiment and very low in 1949. Deep ploughing increased the yield of beet very considerably in 1947, due probably to a very great germination of seedling weeds along with the beet on the shallow ploughed plots, and it increased it a little in four of the other years, but it depressed the yield in 1947, due to the germination and early growth of the beet being very much poorer that year on the deep ploughed plots. The cause of this poorer germination might have been due to a poorer coarser and lumpier tilth on these plots, but apparently similar tilths in other years have not had this depressing effect.

Farmyard manure has definitely increased the yield of beet in each of the six years, being especially marked in the two dry summers of 1947 and 1949.

The effect of depth of ploughing on the responsiveness of the beet to the farmyard manure, which is applied just before the ploughing is done, depends very much on whether potash or phosphate are or are not given. The average yields and responses, as measured by the total quantity of sugar produced, are given in Table 15:—

Table 15. *Effect of Depth of Ploughing on Responsiveness of Sugar Beet to Farmyard Manure* (1944-49)
Total sugar in cwts. per acre

Depth of ploughing	No Potash given			Potash given		
	with FYM	No FYM	Response to FYM	with FYM	No FYM	Response to FYM
12 in.	48·0	41·1	6·9	45·9	45·5	0·4
6 in.	43·6	38·4	5·2	45·9	41·2	4·7
Response to deep ploughing	4·4	2·7		0·0	4·3	
	No Phosphate given			Phosphate given		
12 in.	46·5	42·7	3·8	47·4	43·8	3·6
6 in.	45·4	38·6	6·8	44·2	41·0	3·2
Response to deep ploughing	1·1	4·1		3·2	2·8	

The only conclusions that are worth the drawing, at this stage of the experiment, are that on the whole the crop usually responds about as well to farmyard manure whether it is ploughed in to 6 or 12 inches, and to deep ploughing whether farmyard manure is given or not. But the Table shows that these conclusions do not apply if potash is also given, for it depresses the yield of beet on the deep ploughed plots in the presence of farmyard manure. These conclusions apply equally whether the fertilisers were ploughed in or put in the seedbed.

Potash and phosphate have also increased the yield of beet, and the response has been very marked in some years. But these responses depend very much on the depth of ploughing, how they were applied, and whether farmyard manure was also given.

In the first place, over the six years, the beet only responded to potash and phosphate on those plots not receiving any farmyard

manure, as is shown in Table 16. These fertilisers together were about as effective as farmyard manure, and if the manure is given, no extra benefit was derived from the fertilisers.

Table 16. *Response of sugar beet to farmyard manure and fertilisers*
Total sugar, in cwt. per acre (1944-49)

Fertiliser	None	Potash	Phosphate	Potash and phosphate
No dung ..	39·0	42·4	40·5	44·2
Dung	45·9	46·0	45·8	45·8

In the second place, the beet has given a larger response to potash and phosphate when these fertilisers are broadcast on the land in the autumn before ploughing than worked into the seedbed in the spring. This is shown averaged over the effect of farmyard manure and deep ploughing in Table 14. This result even applies in those plots receiving farmyard manure in which the extra potash or phosphate actually depresses the yield. The depression is greater when the fertiliser is applied to the seedbed than ploughed under. The magnitude of the difference between these two ways of applying the fertilisers also depends on the depth of ploughing, as is shown in Table 17, which gives the mean yields and responses of the beet, measured in terms of the sugar produced, on those plots that do not receive any farmyard manure.

Table 17. *Response of Beet to Potash and Phosphate*
(No farmyard manure given, 1944-49)
Total sugar in cwts. per acre

		Potash		Response to potash	
Depth of ploughing	No potash	ploughed in	in seedbed	ploughed in	in seedbed
12 in.	41·1	46·9	44·0	5·8	2·9
6 in.	38·6	41·8	40·6	3·2	2·0
Response to deep ploughing	2·5	5·1	3·4		

		Phosphate		Response to phosphate	
Depth of ploughing	No phosphate	ploughed in	in seedbed	ploughed in	in seedbed
12 in.	42·7	44·8	42·8	2·1	0·1
6 in.	38·6	41·3	40·7	2·7	2·1
Response to deep ploughing	4·1	3·5	2·1		

* Response to residual effect of ploughing done 3 years previously.

For both potash and phosphate the difference between these two methods of application is larger on the deep ploughed plots than on the shallow, and also the response to deep ploughing is greater when the fertilisers are ploughed in than when put in the seedbed.

The tentative conclusions to be reached from this experiment are, therefore, that in most years sugar beet yields are increased by deep ploughing, and that it is preferable to plough in the potash and phosphate rather than apply them to the seedbed, no matter whether the land is ploughed to 12 in. or 6 in. deep. Further, the response to deep ploughing is greater if the fertilisers are ploughed in than if they are put in the seedbed. Finally farmyard manure applied before ploughing is equally effective if the land is deep or shallow ploughed.

Wheat

The results for wheat are still a little scrappy. A seeds ley was ploughed deep for the first time in the autumn of 1945, so in 1946 the experiment only concerned the effect of deep ploughing on the wheat yield. The autumn of 1946 was so wet that the experimental deep ploughing could not be given before the wheat, so wheat was grown on land that received the experimental treatments in the autumn and spring of 1943-44, and which had been treated uniformly since. Further, the deep ploughing done in the autumn of 1943 could not be done very well, and the full depth of 12 inches was not reached. In the harvest years of 1948 and 1949 the experiment went according to plan. The yields of wheat are given in Table 18:—

Table 18. *Yield of wheat* 1946-49
(Grain in cwt. per acre)

	1946	1947	1948	1949
Yield	29·0	26·8	40·7	43·8
Response to deep ploughing	2·2	—2·8*	—3·5	1·2
Response to dung	—	1·5	2·2	1·6

* Response to residual effect of ploughing done 3 years previously

Clearly no comments can yet be made on the effect of deep ploughing on the wheat crop. There was, however, no question that in 1948 the wheat was a thinner crop on the deep than on the shallow ploughed plots, and the same result seemed to apply to a few of the deep plots in 1946, though the growth of the wheat on the various plots was very erratic that year.

The response of the wheat to dung is interesting. In 1947 and 1948 this was due to a dressing of 10 tons per acre given three seasons previously to sugar beet (which was followed by barley which was undersown to a one-year ley), whilst in 1949 it was to 20 tons given to potatoes in the autumn of 1943 and 10 tons given to sugar beet in the autumn of 1945. Obviously the residual effect of even 10 tons per acre of farmyard manure is still appreciable in the fourth crop.

Oats, Barley (5 *years* 1945-49) *and Ley* (4 *years* 1946-49)

The spring oats is grown after potatoes and the barley after sugar beet, and the barley is undersown with a mixture of a perennial ryegrass and a late-flowering red clover. None of these crops receives any experimental treatment, but both the oats and barley

are given a dressing of sulphate of ammonia in the seedbed, and the barley also receives a dressing of 0·6 cwts. per acre of P_2O_5 as basic slag. The yields and the responses of the crops to the residual effects of the treatments given to the beet and potatoes are given in Table 19:—

Table 19. *Yield and response of oats, barley and ley in cwt. per acre*

	Oats (5 years)		Barley (5 years)		Ley (4 years)
	grain	straw	grain	straw	Hay
Yield	31·3	42·8	34·3	37·2	67·2
Response to the treatment given to the previous root crop					
Deep ploughing ..	—0·2	—0·1	0·7	0·9	0·0
Farmyard manure	1·4	3·8	1·3	3·0	2·5
Phosphate	0·3	—0·6	0·7	0·2	1·0
Potash	0·1	0·2	0·3	1·0	2·4

The yields have been good every year for the barley and the ley, and for 4 years for the oats, but the oat yield was low in 1945.

Deep ploughing has not affected the yield of oats or ley appreciably, but it does appear to have increased the yield of barley a little, and this has been found in every year of the experiment except the first, when the barley was on the land that had not been properly deep ploughed in the autumn of 1943.

The farmyard manure has had a pronounced beneficial residual effect on all three crops, and this has been found in most years for the oats and hay and in all the years for barley. It appeared to depress the yield of oats a little in 1948 and the hay in 1947. It is interesting to note that the barley gives almost the same response to 10 tons of farmyard manure as does the oats to 20 tons.

The response of oats to the residual effect of phosphate and potash is small, but barley grain seems to respond to the phosphate given to the beet and barley straw to the potash. These responses are not large but they have been found consistently each year, and hence are probably real. The response of the ley to the potash given two years previously to the beet is surprisingly large, and for the four years has been 1·5, 1·7, 5·8, 0·6 cwts. per acre respectively. The ley also seems to respond to the phosphate given to the sugar beet, as the responses in the four years have been 1·3, 0·7, 1·0 and 1·1 cwts. per acre. The interesting point of this response is that the barley was given a uniform dressing of 0·6 cwts. per acre of P_2O_5 as basic slag, yet the ley still seems to benefit from the 0·6 cwts. per acre of P_2O_5, given to the sugar beet as superphosphate.

Most of the interactions between the various treatments have been erratic from year to year, but two that have been fairly consistent are relevant to the discussion. The barley straw only responds to potash on those plots that did not receive farmyard manure, in agreement with the sugar beet results, but the ley's response to potash has been about the same on both the dunged and undunged plots.

Summary of the Results of the Deep Ploughing Experiments

The discussion of the results so far has shown that deep ploughing has on the whole given noticeable increases in yield of potatoes and sugar beet without affecting the yield of wheat, barley, spring oats or ley appreciably. This result has an important consequence, for, as already noticed, there are a number of patches on the experimental area where a very tough subsoil clay comes close to the surface. Over these areas the deep ploughed plots have often had a relatively rough and unkind tilth at planting or sowing time, and yet in most years this poor tilth has not affected the yield adversely. Over another part of the area is a much kinder brick earth, which works down more easily to a good tilth, but the young crop on the deep ploughed plots on this area are not usually any more forward than on the areas with the unkind tilth, and there have been occasions when the plant was definitely worse on some of the kinder areas.

Deep ploughing has helped to keep some weeds in control. The most striking example is thistle, which is always much less prevalent on the deep ploughed plots. In 1948 a good deal of poppy was present in many of the spring oats plots but it was less prevalent in the deep than the shallow ploughed areas. In 1947 after a very long winter frost, a great deal of annual weed came up on the shallow ploughed plots drilled to sugar beet or planted to potatoes, and this was much less prevalent on the deep ploughed plots. This was probably the reason why deep ploughing put up the yield of sugar from 34·5 to 46·9 cwts. per acre, or by 12·4 cwts. in that year for this is four times as large as the response in any of the other years.

Finally, this discussion of the results of the deep ploughing experiment may only apply to the particular conditions present in the Rothamsted soil. A large number of simple experiments have been carried out all over the country testing some of these points, and though the results of these experiments have not yet been written up, it is clear that some of the results found at Rothamsted have not been found in most of the other centres.

PUBLICATIONS

Physics Department

1. SCHOFIELD, R. K. 1949. *Calculations of surface areas of clays from measurement of negative adsorption.* Trans. Brit. Ceramic Soc., **48,** 207–213.

An outline is given of the way in which Gouy's theory of ionic equilibrium in the diffuse component of the electric double layer has been extended in order to calculate the deficit of repelled ions per unit area. Combining this calculation with measurements of negative adsorption, estimates are made of the surface area of a sample of bentonite investigated by Mattson. It is shown that the montmorrillonite in this bentonite had separated almost completely in separate 10 A "leaflets." Preliminary measurements with a sample of kaolin give an estimate of surface area in close agreement with the values previously computed from particle size and nitrogen adsorption.

2. PENMAN, H. L. 1949. *A general survey of meteorology in agriculture and an account of the physics of irrigation control.* Q. J. Roy. Met. Soc., **75,** 293–302.

Weather problems in farming fall into three groups. *Statistical* problems include the forecasting of weather for strategical and tactical use in planning farming operations, and the forecasting of crop yields from weather data. *Biological* problems arise in studies of growth and of the spread of disease, and demand a wider knowledge of techniques suitable for use in micro-meteorology. *Physical* problems are largely transport problems in the building up of plant and animal environments.

A typical problem from the last group is the disposal of available solar energy, and it is shown that an energy balance sheet can be drawn up to leave evaporation as the only unknown under prescribed conditions that make the treatment directly applicable to control of irrigation operations. Such an application is described for an experiment on irrigation of sugar beet during the summer of 1948. Results were as satisfactory as the weather of the growing season would permit, the application of a total of 2·6 in. of irrigation (based on weather data) giving a slightly better yield of sugar than a total of 4·7 in. applied whenever expert inspection of the crop decided that irrigation was necessary.

3. SCHOFIELD, R. K. 1949. *The physics of water retention in soil and water extraction by plant roots.* (Paper read at B. A. meeting, Newcastle-on-Tyne, Sept. 1949.)

Surface tension and viscosity account satisfactorily for the behaviour of water in coarse-grained soils. The swelling and shrinking of clay is a distinct phenomenon and appears to be connected with the exchangeable cations which balance the negative charges carried by the clay particles. Several processes are thus involved in the retention of water in soil, but their net effect can be expressed as a potential or free energy. Plants can draw water from soil provided that this free energy throughout the root zone does not sink below a well-defined limit at which 'permanent wilting' occurs.

4. PENMAN, H. L. 1949. *The heat balance of the soil.* (Paper read at B. A. Meeting, Newcastle-on-Tyne, Sept. 1949.)

Recent theoretical and experimental work has made it possible to draw up an energy balance sheet for turf-covered soil. Radiative components include short-wave radiation from sun and sky, and an exchange of long-wave radiation between soil and atmosphere. The net radiant energy retained is shared among three heat sinks:—(i) heating of soil; (ii) heating of air; and (iii) evaporation of water in the process of transpiration. Of these, the third is the most important, for over one-half of the incoming solar radiation is used in providing latent heat for transpiration.

OTHER PAPERS

5. SCHOFIELD, R. K. 1950. *Clay minerals and colloid chemistry. A general introduction.* Clay Minerals Bull. No. 4. (In the press.)

6. PENMAN, H. L. 1949. *Meteorology in agriculture.* Nature, **163,** 591.

7. PENMAN, H. L. 1949. *Weather and farming in India.* Nature, **163,** 696–697.

Chemistry Department

8. BREMNER, J. M. 1949. *Use of the Van Slyke-Neil manometric apparatus for the determination of organic and inorganic carbon in soil and of organic carbon in soil extracts.* Analyst, **74**, 492–498.

Rapid and accurate methods for the determination of organic and inorganic carbon in soils are described. It is shown that the techniques have advantages over established procedures and are suitable for the routine analysis of soils.

9. BREMNER, J. M. 1949. *Studies on soil organic matter. I. The chemical nature of soil organic nitrogen.* J. Agric. Sci., **39**, 183–193.

The acid hydrolysis of six soils with nitrogen contents ranging from 0·1 to 2·38 per cent. has been studied by determining the amounts of ammonia-, humin- and α-amino-N present in the soil hydrolysates after various periods of hydrolysis. Under the conditions of hydrolysis employed (3 ml. of 6 N-HCl/g. soil) the period required for maximum liberation of amino-acids from the soils was about 12 hr. 24·2—37·1 per cent. of the total nitrogen of the soils examined was liberated as α-amino-N in this period. Further hydrolysis led to destruction of amino-acids. Similar amounts of α-amino-N were liberated by hydrolysis of the soils with alkali (5 N-NaOH).

From 69 to 87 per cent. of the total nitrogen of the soils was brought into solution by acid hydrolysis; the amount dissolved by hydrolysing with alkali or with alkali under reducing conditions (alkali-stannite) was not significantly different. It was concluded that most of the insoluble nitrogen found after acid hydrolysis is not derived from protein material, and it was suggested that some of this nitrogen is in the form of heterocyclic nitrogen compounds.

Tests showed that volatile amines could have been present only in traces in the soil hydrolysates. Trytophane could not be detected in either acid or alkaline hydrolysates of the soils. Acid hydrolysates gave positive tests for amino sugars.

The results show that at least one-third of the organic nitrogen of soil is in the form of protein.

10. BREMNER, J. M. and (LEES, H.) 1949. *Studies on soil organic matter. II. Extraction of organic matter from soil by neutral reagents.*. J. Agric. Sci., **39**, 274–279.

A survey of the extracting powers of various neutral reagents has been made to find mild but reasonably efficient methods of extracting organic matter from soil. Sodium pyrophosphate proved to be the most satisfactory of the neutral reagents tested, and the optimum conditions for extraction of organic matter from soil by this reagent have been defined.

11. BREMNER, J. M. 1949. *Studies on soil organic matter. III. The extraction of organic carbon and nitrogen from soil.* J. Agric. Sci., **39**, 284-282.

The amounts of organic carbon and nitrogen extracted from different soils by various inorganic reagents have been determined. The results show that the organic carbon and nitrogen of soil are so intimately associated that, under the influence of any one of the reagents tested, the organic carbon is dissolved only along with, and in proportion to, the organic nitrogen. The relative proportions of carbon and nitrogen extracted vary, however, with both the soil and the extractant.

12. BREMNER, J. M. 1950. *Some observations on the oxidation of soil organic matter in the presence of alkali.* J. Soil Sci., **1**, 198-204.

The results of a study of factors affecting the uptake of oxygen by soil/alkali suspensions are described. It is shown that although little or no uptake of oxygen occurs when soils are treated with neutral reagents, extracts obtained by the use of such reagents contain organic matter that absorbs oxygen rapidly when treated with alkali. Contrary to the work of Chaminade, it was found that oxidation of soil organic matter in contact with alkali did not lead to an increase in the amount of alkali-soluble material.

13. COOKE, G. W. 1950. *Placement of fertilizer for row crops.* J. Agric. Sci. (In the press.)

Fertilizer placed in contact with the seed damaged the germination of sugar beet, mangolds, swedes and peas in 1947; damage was also caused by fertilizer placed directly below the seed. In 1947 and 1948 some damage to the germination of sugar beet was caused by fertilizer in bands three inches

below the soil surface and one inch to the side of the seed; in both years bands of fertilizer three inches to the side of the seed were safe. Where placement of medium or full fertilizer dressings is adopted for row crops, the bands should be placed not less than two inches from the seed to avoid the risk of injury to germination.

All methods of placing gave consistently higher yields of peas than broadcasting fertilizer, the average advantage of placing being over 2 cwt. of peas per acre. In all the experiments on peas in 1948, early applications broadcast and worked deeply into the seedbed were somewhat superior to late applications made at sowing time.

Yields of sugar beet were reduced by methods of applying fertilizer which reduced the plant population. There was little difference between the mean yields for all experiments given by broadcast fertilizer and fertilizer placed in safe positions near the seed. Placed fertilizer promoted much more vigorous growth of sugar beet tops than broadcast fertilizer during spring and early summer but by harvest time this superiority had vanished. Mangolds and sugar beet behaved in much the same way to placed fertilizer.

In experiments on swedes in 1947, average yields were very low due to drought during the summer. Fertilizer placed either directly below or below and to the side of the seed gave consistently higher yields of swedes than broadcast fertilizer.

Placement of fertilizer is of considerable benefit to crops with a short growing season and limited root range and also to crops made sensitive to nutrient deficiency by the poverty of the soil or the immobilisation of nutrients by drought.

14. Cooke, G. W. 1949. *Apparatus for fertilizer placement field work.* Chem. and Ind. 615–618.

The characteristics necessary for special machines used in fertilizer placement experiments are discussed. Commercial placement drills do not deliver fertilizer with the accuracy needed in experimental work. Special apparatus constructed for experiments on potatoes and on other row crops is described. The factors affecting the apparent density of fertilizers and hence the rate of application by top-delivery fertilizer mechanisms were found to be: 1. Compression by the upward force needed to deliver fertilizer. 2. Vibration and jolting. 3. The condition of the fertilizer. The results of experiments on fertilizer placement for potatoes were described.

15. Cooke, G. W. 1949. *Fertilizer placement.* Fertilizer Soc. Proc. No. 6. 1–15. Reprinted in Fertilizer and Feeding Stuffs, **35,** 359–365, 392–398 and Amer. Fertilizer, **110,** 9–11, 22, 24, 26, 28, 30.

A general review of the advantages of placement, the special machines needed for experiments and the results of experiments on cereals, potatoes and other row crops.

16. Cooke, G. W. 1949. *Recent developments in fertilizer placement.* Farming, **3,** 231.

A review of recent experimental work on potatoes, mangolds, swedes, sugar beet and threshed peas.

17. Cooke, G. W. 1949. *Fertilizer placement.* World Crops, **1,** 32.

A general review of placement practices in Britain and in other countries. The results of recent experiments on cereals and on row crops are stated.

18. Cooke, G. W. 1949. *Fertilizer placement experiments.* Agric. Eng. Record, **2,** 227–229.

The results of experiments on fertilizer placement for potatoes are discussed.

19. Crowther, E. M. 1949. *Field experiments as the basis for planning fertilizer practice.* U.N. Conf. on the Conservation and Utilization of Resources. Experience paper prepared for Section Meetings: Land Resources 5(a) Improving Soil Productivity.

Extensive series of field experiments are needed to establish the general principles of manuring, to compare new forms of fertilizers or methods of applying them, and to determine the returns for various rates of application. The problems of determining the optimal amount of fertilizer to provide and the best way to distribute it became particularly acute in the United Kingdom from 1940 onwards. Each farmer received a fertilizer permit based on fixed rates for specified tillage crops and additional allowances for soils known to be specially deficient her in eitphosphate or potash. The rates

were determined to ensure the highest marginal returns for additional imports.

Principles of fertilizer allocation can be established by using an expression for the Law of Diminishing Returns to bring together results from all available field trials and to calculate the most profitable dressings. Fertilizers are used to best advantage when all fields are manured to a constant amount below the most profitable dressings, due allowance being made for local soil and climatic conditions and the use of dung.

Although the approximate form of the response curves relating yields to amounts of fertilizer are known sufficiently well for interpolation within the range of dressings realized in practice, it is dangerously misleading to use arbitrary constants not determined from the field experiments themselves. Mitscherlich's nitrogen factor implies grossly exaggerated maximal responses, which have been used by Willcox for extravagant claims about the potentialities of fertilizers.

20. Crowther, E. M. 1949. *The effects of plants and animals on soil fertility. A review of Rothamsted work.* Specialist Conf. in Agriculture, Australia. 1949. Section D: Soil Fertility.

The effects of systems of land management on soil productivity provide some of the most important and most difficult problems in agricultural science. Early attempts at analysing the factors involved are reviewed in terms of the pioneering work of Lawes, Gilbert and Warington. Attention is drawn to the marked influence of climate on the responses to manurial treatments. Relatively few field experiments have yet been carried out to test the long-term effects of alternative rotations, including leys and fallow, and the residual effects of crop residues and manures, but some progress has been made in the more formal problems of design. Pioneer experiments at Woburn, Rothamsted and the Sudan Gezira are described. Similar experiments are urgently needed in many countries and particularly in the tropics.

21. Crowther, E. M. 1949. (As contributing joint author). *Efficient use of fertilizers.* Edited by V. Ignatieff, F.A.O. Agric. Studies, No. **9**, 183 pp.

A co-operative review by many authors of current problems and practices in the use of fertilizers and manures.

22. Crowther, E. M. 1949. *The effect of potassium and sodium fertilizers on the yield and composition of sugar beet.* 12th Congress Inst. Inter. de Recherches Betteravieres, Annexe III.

The results of several series of field experiments on sugar beet are reviewed in relation to the effects of sodium and potassium chlorides on yield, the uptake of sodium and potassium by the plant, the time of application of sodium chloride and the relative effects of sodium nitrate and ammonium sulphate, when used alone and with sodium chloride. For practical agricultural purposes potassium and sodium may be regarded as almost interchangeable for sugar beet and mangolds, but not, of course, for most other crops which can absorb only small quantities of sodium.

23. Crowther, E. M. 1949. *Condition in fertilizers.* Fert. Soc. Proc., No. **5**, 1–8.

A review of current problems in the storage and use of fertilizers on the farm with special reference to hygroscopicity, "drillability," the use of conditioners and the comparison of granular and powdered fertilizers.

24. Crowther, E. M. 1948. *Soils and fertilizers.* J. Roy. Agric. Soc., **109**, 71–82.

25. Deb, B. C. 1949. *The movement and precipitation of iron oxides in podzol soil.* J. Soil Sci., **1**, 112–122.

Consideration of the mechanisms proposed for the movement of iron in podzol profiles suggested that the iron moved either as a negatively charged humus-protected iron-oxide sol or as a complex organic ion.

In a study of the mutual coagulation and peptization of iron oxide and humus sols it was found that the amount of humus necessary for the full peptization of a sol containing 100 parts of iron oxide per million parts of solution with a pH value around 4·0 was not more than about one-third the amount of iron oxide. This is a much smaller ratio of humus to iron oxide than was formerly believed to be necessary.

No evidence could be found to support the view that precipitation of iron from humus-protected sols is effected by exchangeable calcium in the B

horizons of podzols or that the adsorption of iron from complex salts of organic acids is influenced by the pH or amounts of exchangeable bases present in the soil. It therefore appears necessary to postulate a microbiological mechanism for the precipitation of iron.

26. Heintze, S. G. 1949. *Liming experiments on light land at Tunstall. Part 2. Soil reaction and loss of lime.* J. Roy. Agric. Soc., **110**, 98-103.

Soil samples were examined periodically from an experiment started in 1932 on a light sandy soil at Tunstall, Sussex. The soil had initially a pH value of 4·6 and a "lime requirement" by the Hutchinson-McLennan method of 17 cwts. $CaCO_3$ per acre. 0,1,2,3,4,5 tons ground chalk per acre were compared in a 5 × 5 Latin square. For the first few years, when sodium nitrate was used, the pH values remained steady and the annual loss from the limed plots amounted to about 2·3 cwt. $CaCO_3$ per acre. When sodium nitrate was replaced by ammonium sulphate the loss of lime from the limed plots was rapidly increased. In the early years of the experiment sugar beet failed on soils with pH around 5·0 but fair crops were obtained where only 1 ton $CaCO_3$ per acre had been given. Towards the end of the experiment a modest crop was obtained on plots in which the pH of the surface soil had fallen to pH 5·0. The crops on these plots must have utilized subsoil calcium retained from the dressings of chalk many years earlier.

Pedology Department

27. Bloomfield, C. 1950. *Some observations on gleying.* J. Soil Sci. (In the press.)

The gleying reaction may be produced in the laboratory by incubating soil in a sugar medium. Under these conditions the chief effect is the removal of amorphous ferric oxide coating the clay particles of the original material. The grey colour of the gleyed clay appears to be due to small amounts of organic that are which is concentrated with the smaller particles of the clay fraction.

28. Brown, G. 1950. *Location of the exchangeable cations in montmorillonite.* Clay Minerals Bulletin. (In the press.)

The exchangeable cations in the glycerol-montmorillonite complex have been shown by Fourier methods to take up a position midway between the inorganic layers. The Fourier curves also lend support to the structure proposed by Hofmann for montmorillonite rather than that suggested by Edelman.

29. Brown, G., and Macewan, D. M. C. 1950. *The interpretation of X-ray diagrams of soil clays. II. Structures with random interstratification.* J. Soil Sci. (In the press.)

Graphs are presented showing the calculated basal plane scattering (using the Hendricks-Teller formulae) for mica, or montmorillonoid, and kaolin-type structures with randomly interstratified layers of water or glycerol. The application of such graphs to the identification of random mixtures in soil clays is discussed.

30. Chenery, E. M. 1949. *Aluminium in the plant world. II. Monocotyledons and Gymnosperms.* Kew Bull., No. **4.**

Every family of monocotyledon and every genus of gymnosperm were examined for aluminium-accumulators. They were found only in the rare tropical family Rapateaceae and in the anomalous genus Aletris of the Liliaceae. They were entirely absent from the gymnosperms.

31. Chenery, E. M. 1949. *Aluminium in the plant world. III. Cryptogams.* Kew Bull., No. **4.**

In the ferns and fern allies aluminium-accumulators were found almost exclusively in the most ancient families: Lycopodiaceæ, Marattiaceæ, Matoniaceæ, Gleicheniaceæ, Cyatheaceæ, Loxsomaceæ, Dipteraceæ, Plagiogyriaceæ, the genera Cheiropleuria and Tapeinidium of the Polypodiaceæ and three anomalous species of Blechnum. In the mosses aluminium-accumulators occur chiefly in the ancient sub-class Andreaobrya and the advanced families Polytrichiaceæ and Dawsoniaceæ.

32. MacEwan, D. M. C. 1949. *The mineralogical analysis of clays by X-rays.* Research, **2**, 462.

An account of recent advances.

33. MacEwan, D. M. C. 1950. *Tres conferencias sobre la estructure cristalina de los minerales arcillosos.* Anales de Edafologia. (In the press.)

A summary of clay mineral work done in this Department, together with a provisional classification and nomenclature of clay minerals, as used here in describing the results of X-ray analysis.

34. MacEwan, D. M. C., and Amoros, J. L. 1950. *Investigacion roentgenografica de las arcillas.* Anales de Edafologia. (In the press.)

A summarised description of the techniques of clay mineral analysis used here, together with a table of X-ray spacings and intensities.

35. Mac Ewan, D. M. C. 1950. *The montmorillonoid minerals.*
Brown, G., and MacEwan, D. M. C. 1950. *Structures with random interstratification.*
(Grim, R. F., Bradley, W. F.), and Brown, G. *The mica clay minerals.* Three chapters of the monograph on "The Identification and structural relationships of clay minerals," published by the Clay Minerals Group of the Mineralogical Society. (In the press.)

They include tabular and graphical representations of the available data for the identification, using X-rays, of the minerals in question, and full discussions of the use of such data.

36. Muir, A. 1949. *Geochemistry* in Metals Handbook. Butterworth.

37. Stephen, I., and MacEwan, D. M. C. 1950. *Chloritic clay minerals in the Keuper Marl.* Clay Minerals Bull., No. **4.** (In the press.)

Two new types of chloritic mineral were described in this paper. The first, found in a Keuper marl from near Birmingham is a hydrated chlorite analogous to hydrated micas, with interlamellar water molecules.

An X-ray investigation of samples of Keuper Marl from a dam construction site at Blithefield Reservoir, Staffordshire revealed the presence of a related chloritic material, with swelling properties analogous with those of the montmorillonoids. On glycerol treatment the material shows an expansion from 14A to 17·8A, corresponding to one layer of glycerol molecules between the chlorite sheets. Glycerol-montmorillonoids also give a 17·8A reflection, but the minerals can be distinguished by heating to 500° C., the chlorite giving a 14A reflection, whereas with montmorillonoids the spacing is condensed to 10A.

Soil Microbiology Department

38. Crump, L. M. 1950. *The influence of the bacterial environment on the excystation of amoebæ from soil.* J. Gen. Microbiol. **4,** 16-21.

Cysts of two amœbæ from soil were grown in single cell cultures to test the effect upon excystation of the presence or absence of bacteria, age and type of bacteria, age of cyst, and the concentration of sodium chloride. Within the limits of the experiments excystation in one species was independent of the presence of bacteria, and unaffected by their age and type or by the age of cyst. The other was more sensitive and could not excyst without living bacteria of a suitable type, and the cysts become less likely to develop with age. Excystation in both species was adversely affected by increasing the concentration of sodium chloride, distilled water giving the best results.

39. Erikson, D. 1948. *Differentiation of the vegetative and sporogenous phases of the Actinomycetes. 3. Variation in the* Actinomyces cœlicolor *species-group.* J. Gen. Microbiol., **2,** 252–259.

Variation in the Actinomyces cœlicolor species-group comprises loss of pigment and aerial mycelium, and occasionally of agar liquefaction. Stable variants may arise from degenerate, aged, vegetative mycelium, but do not normally do so when the vegetative mycelium is kept in vigorous condition by frequent subcultivation in suitable media. Single spore isolations from the aerial mycelium of typical and of variant colonies show that there may be inherent differences in the sister-spores of the same chain. Thus, in an agar-liquefying strain 3 of 15 spores had lost the power to produce pigment and to liquefy agar; and an atypical colony of the same strain yielded three viable isolates each with a strong tendency towards sectoring, with the ultimate production of a colourless, non-agar-liquefying variant as well as the typical growth. A non-agar-liquefying strain, which by prolonged cultivation in the vegetative phase had lost its power of producing the red-blue indicator pigment, yielded a variant giving rise to sectored colonies with occasional

restoration of the blue pigment. Spontaneous occurrence of variants may be detected in certain spores of the aerial mycelium of well-grown typical colony, although it is more readily seen in the spores of degenerate colonies which have been rendered atypical by artificial methods of cultivation.

40. Erikson, D. 1949. *Differentiation of the vegetative and sporogenous phases of the Actinomycetes.* 4. *The partially acid-fast Proactinomycetes.* J. Gen. Microbiol., **3**, 361–368.

About three hundred strains of proactinomycetes were isolated from Rothamsted soils and examined together with certain strains from the National Collection of Type Cultures and other sources. Although little more than 9 per cent. were partially acid-fast on immediate isolation, subcultivation on rich media such as milk or nutrient glucose broth increased the percentage to 31 per cent. The strains showed a range of features, from the soft mycobacterial type of growth with transient vegetative mycelium and very sparse aerial mycelium, if any, to the harder, more actinomycete-like variety. Of the acid-fast species *Proactinomyces opacus*, *Proactinomyces salmonicolor*, and *Proactinomyces paraffinæ* predominated. In all, ninety-two strains were observed continuously for nearly two years on a variety of complex and simple media, and were stained at frequent intervals. Acid-fast cell elements occurred more often in complex protein- and fat-containing media, and in chemically defined media containing paraffin or large quantities of glycerol. They varied in shape and size according to the species and the age and quality of the growth. It is thought that differences of permeability of the cytoplasmic membrane in different environments may account for these variations. No evidence was obtained of any 'resting spores' or 'chlamydospores' in the vegetative mycelium. Since there are no true spores in the aerial mycelium when it is present, the proactinomycetes in general may be regarded as asporogenous.

41. Erikson, D. 1949. *The morphology, cytology and taxonomy of the Actinomycetes.* Ann. Rev. Microbiol., **3**, 23–54. (Review.)

42. Kleczkowska, J. 1950. *A study of phase resistant mutants of* Rhizobium trifolii. J. Gen. Microbiol. (In the press.)

Phage resistant mutants were obtained from four strains of *Rhizobium trifolii*. Mutations to phase resistance tended to coincide with mutations in other features, such as morphology of colonies or effectiveness in nitrogen fixation. The accompanying mutations occurred independently, and their frequency varied widely from strain to strain.

Some mutants seemed stable in their newly acquired features, whereas some others continued to mutate at high rates.

Some of the mutants as regards nitrogen fixation were stable or could eventually be stabilised but others derived from one of the parent strains remained unstable even after replating or reisolation from nodules.

43. Meiklejohn, J. 1949. *Isolation of* Nitrosomonas *from Rothamsted soil.* Nature, **164**, 667.

Nitrosomonas europaea Winogradsky, a bacterium which oxidises ammonia to nitrate, has been isolated in pure culture from the soil of Broadbalk field, Rothamsted.

44. Meiklejohn, J. 1949. *Reduction des nitrates et anærobiose.* Ann. Inst. Pasteur, **77**, 389–394.

In a review of the present state of knowledge on nitrate reduction by bacteria, it is argued that, of the two reduction products important in the nitrogen cycle in soil, nitrogen gas is produced by facultative anærobes, and ammonia by strict anærobes. Reduction to nitrogen (denitrification) requires a suitable organic compound to act as a hydrogen donator, but reduction to ammonia uses hydrogen itself. Whether nitrogen or ammonia is formed in nature by reduction of nitrate depends on the oxidation-reduction potential of the surroundings, and on the hydrogen source available.

45. Meiklejohn, J. *The isolation of* Nitrosomonas europaea *in pure culture.* J. Gen. Microbiol. (In the press.)

The method used to isolate *Nitrosomonas europæa* was a modification of that invented by Winogradsky. It involved (1) building up the population of nitrifiers in enrichment cultures; (2) removal of the bacteria from chalk particles in the enriched culture with a stream of carbon dioxide; (3) picking colonies from poured silica gel plates. The organism isolated has small oval cells, 1·2 — 1·7 × 1·0 — 1·2μ, is non motile and Gram-negative. On silica

gel it forms minute colonies, only 100 μ across; it oxidises ammonia to nitrite in a mineral medium.

46. NUTMAN, P. S. 1949. *Physiological studies on nodule formation. II. The influence of delayed inoculation on the rate of nodulation in red clover.* Ann. Bot. N.S , **13**, 261–283.

The rate of nodule formation on red clover growing on a N-free medium is influenced by the time at which inoculation is made. With an effective strain of bacteria moderate delay, up to about 20 days from sowing, leads to an increase in rate of nodule formation which is maintained. Longer delay is followed by discontinuous nodulation, the rate being at first normal and then ceasing altogether for varying periods depending on the duration of pre-inoculation growth.

With ineffective strains of bacteria delay in inoculation always results in a lower rate of nodule formation.

These results are interpreted in terms of root morphogenesis, as follows. Infection is limited to (i) the zones of the root bearing developing root hairs and (ii) the foci from which lateral roots normally develop. Development at these points of incipient meristematic activity is regulated by the production of an inhibitor in the root and nodule meristem. Thus, normal nodule formation with an effective strains leads to a lowering of the meristematic potentiality of the root by the replacement of inhibitory but self-reproducing laterals with inhibitory and non-self-reproducing nodules. Delay in inoculation thus allows the development of a larger actively reproducing meristematic system with a higher susceptibility to infection.

With ineffective strain inoculation the nodule meristem is ephemeral and therefore non-inhibitory so that delayed inoculation does not result in an enhanced rate of infection. On this view the larger number of nodules produced by an ineffective strain is a result of the degeneration of the nodule meristem.

47. NUTMAN, P. S. 1949. *The nuclear and cytoplasmic inheritance of resistance to infection by nodule bacteria in red clover.* Heredity, **3**, 263–291.

The heredity resistance described is due to a simple recessive factor (r) which acts in conjunction with a maternally transmitted component (cytoplasmic factor σ). Wild susceptible plants appear to be of two types heterozygous for the factor r, and homozygous dominant. Susceptibles of both types breed true; the recessive homozygote being lethal in the absence of σ cytoplasm. Crosses between resistant plants and related susceptibles and among derived susceptibles show normal segregation of resistant plants except where an intercalary susceptible generation is interposed. Here there is a zygotic and post-zygotic elimination of resistants which may be due to the dilution of the cytoplasmic factor.

Resistant plants breed true in most families and where they do not breeding experiments suggest the existence of supplementary genetic susceptibility factors. Resistant plants are generally less vigorous than susceptibles and show growth abnormalities. Root hairs of resistant plants show curling in presence of nodule bacteria but are not penetrated. On grafting no transference of resistance or susceptibility occurs. The gene is not linked with the sterility alleles (S) and is inherited independent of factors determining early or late nodulating habit, the number of nodules formed, and a recessive factor (i) for ineffectiveness in N. fixation.

In the experimental stocks six simple recessives factors affecting appearance of leaf, flower and root were identified; these were not more frequent in resistant lines than elsewhere. Other genetically indetermined abnormalities were, however, more frequent in the outcrosses of resistant plant than in the reciprocal crosses due to the presence of σ cytoplasm.

48. NUTMAN, P. S. 1949. *The influence of strain and host factors on the efficiency of nitrogen fixation in clover.* British Specialist Conf. on Agriculture, Australia, 1949.

49. SINGH, B. N. 1949. *The effect of artificial fertilizers and dung on the numbers of amœbæ in Rothamsted soils.* J. Gen. Microbiol., **3**, 204–210.

The total numbers (active + cystic) and the numbers of active amœbæ in plots treated with complete minerals + ammonium sulphate and with farmyard manure were much higher than in the untreated plots. The complete minerals plot of Barnfield had a just significantly lower total count of

amœbæ than the farmyard manured plot, although no significant difference existed between the counts of active amœbæ. The difference in the numbers of both the total and the active amœbæ between the complete minerals and farmyard manure-treated plots on Broadbalk was not significant. No correlation was found between the percentage of organic carbon in the soils and the number of amœbæ.

50. SWABY, R. J. 1949. *The relationship between micro-organisms and soil aggregation.* J. Gen. Microbiol., **3**, 236–254.

The physical condition of soil is improved by adding readily decomposable organic material. Microbial cells and metabolic products affect soil structure by binding loose soil particles into water-stable aggregates.

Experimentally, the relative aggregating power of pure cultures of micro-organisms was as follows: fungi > actinomycetes and a few gum-forming bacteria > many gum-producing bacteria > yeasts, proactinomycetes, and many bacteria; the last three groups did not improve aggregation. Fungal hyphæ entangled soil particles into stable aggregates; weaker crumbs were formed by the frailer threads of actinomycetes. A few bacterial strains produced gums capable of glueing soil into water-stable aggregates, but the majority of bacterial slimes were almost useless because they remained water-soluble after drying. The cementing properties of these gums was not improved by treatment with H or Ca ions. Bacterial gums stabilized the aggregates produced from completely dispersed soils and kaolin, but not those formed with bentonite or ferric hydroxide. The pH value of the soil played a very minor part in influencing the aggregation produced by pure cultures of micro-organisms or even by soil inoculum.

Mixed cultures of fungi or of actinomycetes gave slightly better aggregation than pure cultures, but neither capsulated nor non-capsulated bacteria in mixtures gave better results than single strains. More complex mixtures containing fungi, actinomycetes and bacteria gave good aggregation when all micro-organisms were compatible, but poor results when antagonistic bacteria inhibited the growth of either fungi or actinomycetes. The fair aggregation obtained with soil inoculum as reproduced in the laboratory by inoculating sterilized soil with complex mixtures of micro-organisms.

A study was made of the relative merits of glucose, starch, blood, yeast, fungal mycelium, straw clover and farmyard manure for encouraging aggregation by mixtures of fungi, actinomycetes and bacteria.

Aggregates bound by mycelia did not last long because the hyphæ were decomposed by bacteria. The temporary improvement of soil structure after the addition of organic materials can be partly explained by the action of microbes, but the permanent crumb structure of many soils must be due mainly to other causes.

51. SWABY, R. J. *Influence of humus on soil aggregation.* J. Soil Sci. (In the press.)

Several methods were used for extracting humus from a number of widely different soil types. The cementing power of the various humates was tested by mixing them with soil and determining the weight of water stable aggregates surviving wet sieving. In general α humic acid > Tuilin's group 2 b. humates > group 2 a humates > group 1 humates > fulvic acid. Greater stability was obtained when the humates were fixed as films over the soil particles by H or Ca ions.

An attempt was made to fractionate humic acid into its component colloidal cements without success. Various chemical treatments, such as hydrolysis, deamination, esterification and acetylation, modified the glueing qualities of humic acid, suggesting that colloidal substances with NH_2, COOH and OH polar groups were partly responsible for the cementing action of humates.

A study was made of the influence of various organic substances on soil aggregation. Resins, fats and some proteins cemented soil into aggregates so impervious to water that slaking was prevented. Some microbial gums and other polysaccharides acted as good soil glues, while others were useless. Lignates were only slightly inferior to humates as soil cements, but tannin and cationic detergents were of little value. The glueing properties of proteins and polyuronides were considerably altered by various chemical treatments.

The structure of puddled soils was sometimes restored by repeatedly wetting, incubating and drying them. Acid, lateritic soils high in sesquioxide cements were rapidly restored; chernozems containing much colloidal humus

and clay took longer, but other types showed little improvement even after prolonged treatment. Sterilization of soil rendered the humus more available for micro-organisms, which then able to improve soil structure temporarily. Micro-organisms reduced the stability of aggregates cemented by films of calcium humate.

52. Swaby, R. J. 1950. *Influence of earthworms on soil aggregation.* J. Soil Sci. (In the press.)

The experiments indicate that earthworms only improve the structure of soils well supplied with nutritive organic matter. An abundant food supply increases the number of intestinal bacteria some of which produce gums and glue the casts into stable aggregates. Under the conditions of restricted aeration inside the earthworm fungi do not flourish. This mechanism for increasing the stability of worm casts differs from that produced directly in soil by the incorporation of readily decomposable material, where the effect of fungal mycelium is more important than that of slime producing bacteria.

Botany Department

53. Brenchley, W. E. 1949. *The use of weedkillers on paths.* Gardener's Chronicle, **125**, 124.

54. Humphries, E. C. 1950. *Wilt of Cacao Fruits* (Theobroma Cacao). *V. Seasonal variation in potassium, nitrogen, phosphorus and calcium of the cacao tree.* Ann. Bot., **14**, 149-164.

The seasonal changes in potassium, phosphorus, nitrogen and calcium in the bark and wood of the cacao tree at levels of 1 ft., 6 ft., and 12 ft., from the base of the trunk were followed over a period of 14 months. A consideration of the negative gradients of calcium in the wood indicated that uptake of minerals from the soil had practically ceased before the end of the dry season. There was a negative gradient of potassium between 1 ft., and 6 ft., and a positive gradient between 6 ft., and 12 ft., indicating a predominately structural and storage gradient in the lower part of the trunk and a dynamic transport gradient in the upper. The dynamic gradient increased and the storage gradient decreased at times of greatest demand on the potassium reserves. Similar gradients and changes occurred in the case of total nitrogen and non-carbohydrate alcohol-soluble material.

Statistical analysis showed that potassium was depleted as size of crop increased and also that potassium was the chief factor limiting crop size.

55. Watson, D. J. 1950. *Inflammability of cereal crops in relation to water content.* Empire J. Expt. Agric. (In the press.)

Field crops of barley became inflammable, in the sense that a fire continued to spread indefinitely and did not die out spontaneously, when the water content of the straw fell below about 30 per cent. of fresh weight.

In laboratory tests, a flame was propagated indefinitely along a single wheat or barley straw when its water content was lower than about 30 per cent. In barley, a node acted as a barrier to the passage of flame along an isolated stem when the water content was above 25 per cent.

In 1941, an abnormally wet season, the water content of oat and wheat straw of field crops never fell below the critical value for inflammability; that of barley straw fell to the critical value only when the crop was left standing for two weeks after it was dead ripe. It is suggested that delay in harvest after the stage when the crop becomes fit for cutting is probably the chief source of fire risk.

A multiple regression on time, accummulated rainfall, and daily maximum temperature accounted for 50-80 per cent. of the variance between sampling times in the water content of the straw of wheat and barley crops. The water content of oat straw was apparently not dependent on rainfall. The water content of barley straw was more sensitive to rainfall and temperature than that of wheat straw. Most of the position deviations of observed values of water content from the values calculated from the regression equations occurred on days when surface moisture was present on the plants.

Statistics Department

SCIENTIFIC AND TECHNICAL PAPERS

56. Boyd, D. A., Crowther, E. M., Moffatt, J. R. and Yates, F. 1949. *A grazing experiment on the residual manurial value of feeding stuffs consumed on grass.* J. Roy. Agric. Soc.

A grazing experiment has been conducted on old pasture at Rothamsted over twelve seasons to compare the residual manurial value of feeding stuffs with those of the fertilizer equivalents given in current residual value tables.

Nine plots, each of about five acres, were arranged in three blocks and grazed in a three-year cycle. In the first year of each cycle the plots of one block were grazed by cattle, those on one plot of the block receiving additional feeding stuffs. A second plot received the estimated fertilizer equivalent in the following winter or early spring and for two seasons the three plots were grazed by cattle and sheep in a fixed ratio of grazing days. The manurial effects were estimated from the live-weight increases and the maintenance requirements.

Over the whole period of the experiment the fertilizers and the residues from the feeding stuffs each increased the total output of the plots by nearly one-tenth. Although this result supports the current tables of residual values, it is subject to great uncertainty through the irregularities inevitable in experiments on large plots with few replicates.

The experiment has provided valuable guidance for future grazing trials. In seeking a compromise between the requirements for good management and good experimental design, the present tendency is to use much smaller plots and to estimate the productivity of the individual plots by cutting, weighing and analysing the herbage.

57. Cox, P. M. 1949. *Rectangular two-dimensional lattices.*

The paper extends the theory of two-dimensional lattices to the case of pq varieties or treatments, where p and q are similar, but not equal, in magnitude, thus increasing the range of available lattice designs. Blocks are not all of the same size, there being q blocks of p plots and p blocks of q plots in each pair of replications.

58. Dudley, F. J. and Read, D. R. 1949. *The design of experiments in egg production of poultry.* Harper Adams Utility Poultry J., **34**, 3–20.

The systems adopted for keeping poultry for egg production are presented, and discussed from the viewpoint of the experimenter. The organisation and administrative aspects of experimental work in this field are briefly reviewed.

Reference to earlier work points to the necessity for improvement in experimental procedure and this is substantiated by certain analytical evidence.

It is emphasised that adequate replication of experimental units must be made in order to achieve efficient operation and the attainment of valid conclusions, and this point particularly is to be borne in mind in considering the establishment of new experimental plant.

The possibilities of adopting more efficient designs are discussed.

59. Grundy, P. M. 1949. *The estimation of error in rectangular lattices.* Biometrics, **6**, 25–33.

The rectangular lattices considered are those for $p(p + 1)$ varieties in blocks all of p plots. The opportunity is taken to record the formulae for any even number of replications. Formulae for estimation of error are given which have some technical advantages over those suggested by Harshbarger, and are also simpler.

60. Grundy, P. M. and Healy, M. J. R. 1949. *Restricted randomization and quasi-Latin squares.* J. R. Statist. Soc. (Series B). (In the press.)

Ordinary randomization of designs for factorial experiments sometimes has the unfortunate result that some main effect is measured by a contrast obviously liable to be inaccurate. In this paper a new type of restricted randomization is described, which preserves the property of giving an unbiased estimate of error variance, and at the same time excludes certain patterns likely to be particularly inaccurate. Applications to the 8×8 quasi-Latin square, and to other designs for factors at two and three levels are given, and the general question of the validity of experimental designs is briefly discussed.

61. Healy, M. J. R. 1949. *Routine computation of biological assays involving a quantitative response.* Biometrics, **5**, 330–334.

A nomogram is described for rapid computation of routine biological assays using a 6-point design.

62. Jolly, G. M. 1949. *Use of probits in combining percentage kills.* Ann. Appl. Biol. (In the press.)

The problem is discussed of how to combine percentage kills obtained in an experiment repeated under different sets of conditions. Interaction of treatments with replicates is defined in terms of probits, and, assuming the absence of such interaction, a method is evolved of finding maximum likelihood estimates of the treatment differences. An example is used to illustrate details of the method.

63. Patterson, H. D. 1949. *The statistical analysis of certain long-term experiments.* Thesis for M.Sc., University of Leeds.

The thesis is divided into three parts. Part I consists of a discussion of the methods of analysis appropriate to experiments in which each unit (e.g. plot in field trial) is associated with a single treatment. These methods differ according to the structure of the underlying variation. In Part II the analysis of a certain type of fixed crop-rotation experiment, of which the three-course rotation experiment at Rothamsted is an example, is considered.

Part III deals with experiments over several periods in which each unit is associated with a given cycle of treatments. These are of considerable importance, particularly in connection with animal nutrition research. The number of possible cycles of length p periods from t treatments is $\frac{t^1}{(t-p)!}$, usually very large, but in many cases suitable designs are available for only a fraction of this total number. Methods of analysis are developed for designs in which there are t(t—1) units in blocks of t based on complete sets of orthogonal Latin squares or rectangles. This analysis is not difficult if residual effects do not persist for more than one period and direct and residual effects are additive. Systematic elements may, however, enter into the uncontrolled variation, and produce biases in the analysis of variance. It is shown how 'inter-unit' information, which may be of importance when t is much greater than p, may be utilized.

Some consideration is also given to the more complicated cases in which there are

(1) direct effects, and several residual effects but no interactions;
(2) direct effects, single residual effects and single interactions.

64. Patterson, H. D. 1949. *Design and analysis of change-over trials. Parts I and II.* J. Agric. Sci. (In the press.)

The use of designs involving Latin squares in certain long-term experiments, particularly those connected with animal nutrition research, has been advocated in recent years. When there are no residual effects of treatments it is easy to see that these designs are valid, but in other cases it is shown that certain difficulties arise and these difficulties are examined. A method of analysis taking into account the ordering of the periods is developed.

In many cases it is essential to keep the total number of experimental units (e.g. cows), and periods as low as possible so that the use of Latin squares is rather limited. Consideration is given to designs based on Latin rectangles (incomplete squares) and to designs involving the principles of confounding and incomplete blocks of single period experiments.

65. Read, D. R. 1949. *Study of the accuracy of simple sampling methods for the estimation of egg production and mean egg weight.* J. Agric. Sci., **39**, 260–264.

Sampling methods for the estimation of annual production and mean egg weight have been examined, and an attempt made, by a combination of theoretical considerations and practical observations, to derive general expressions for the standard error of such estimates. Numerical values of these errors have been tabulated in a form suitable for direct application by the practical poultry worker.

66. Yates, F. 1949. *The place of experimental investigations in the planning of resource utilization.* U.N. Conf. on the Conservation and Utilization of Resources. Paper prepared for Plenary Meeting: Methods of Resource Appraisal 9(a).

Experimental investigations are of use not only in fundamental scientific research, but also in the technological research required to establish "scientific know-how." It is this latter type of experiment which is of particular value in planning resource utilization.

Technological experiments introduce new problems of experimental design, and their efficiency has been very greatly increased during recent years by the development of this subject. They constitute a new and still developing technique of which the possibilities are as yet imperfectly realised.

The paper outlines the considerations governing the planning of technological experiments for resource utilization, and discusses their relation to surveys and other forms of observation. The problems encountered in agricultural development are specially considered. Questions that arise are the degree to which experiments should attempt to mirror practical conditions, how far a problem can be broken down into component parts for experimental purposes, the degree of replication that is required in space and time, the place of large-scale pilot experiments, allocation of resources to the different problems, and the timing of experimental work in relation to other work required in planning for resource utilization.

67. YATES, F. 1949. *Agriculture, sampling and operational research.* Proc. Inst. Int. Statist. (In the press.)

The paper describes the use of sampling methods and surveys in what it is fashionable to call "operational research," for which a suggested definition is given as: "the application of the methods of scientific research to problems arising in administration and planning." Operational research involves a combination of observation (including surveys), experiment, and reasoning (both deductive and inductive). The qualifications which are needed of operational research workers are discussed, and two examples of operational research in the agricultural field are described. The first is the work carried out on the utilization of fertilizers in the United Kingdom during the war, the second is the investigation now in progress into the growing of potatoes.

68. YATES, F. 1949. *Experimental technique in plant improvement.* Biometrics. (In the press.)

The paper discusses the problems which arise when planning a testing scheme for the large number of new lines and varieties which are produced in the course of any programme of plant improvement.

69. YATES, F. 1949. *Bases logiques de la planification des expériences.* Ann. Inst. Poincaré. (In the press.)

The general theory entering into the design of experiments and into inductive inferences from their results is developed, with particular attention to the implications of randomisation.

70. YATES, F. 1949. *Quelques developpements modernes dans la planification des expériences.* Ann. Inst. Poincaré. (In the press.)

Various developments in modern experimental design which are of general mathematical interest are described. The principle of restricted randomisation, which enables particularly unfavourable randomisation patterns to be avoided without biasing the estimate of error, is here described for the first time.

71. YATES, F. 1949. *Quelques developpements récents dans la théorie des sondages. I. Methodes appropriées à des unites de sondage de taille différente.* (Communication to the Institut de Statistique de Paris.)

The methods of sampling applicable to sampling units of different size, and the various methods of estimation that can be used in conjunction with them, are described. The paper presents certain new results in connection with the estimation of error when a stratified sample with variable sampling fraction is used and the domains of study cut across the strata.

72. YATES, F. 1949. *Quelques developpements récents dans la theorie des sondages. II. Sondages à plusieurs degrés et à plusieurs phases.* (Communication to the Institut de Statistique de Paris.)

The paper gives an account of the ramifications of multi-stage and multi-phase sampling and the various methods which can be adopted for the estimation of errors and relative efficiency.

REPORTS

73. BOYD, D. A., DYKE, G. V. and CREASEY, Monica A. 1949. *Survey of maincrop of potatoes,* 1948. Reports for National Agricultural Advisory Service Provinces. West Midland, East Midland, Montgomeryshire, South Western, Northern, South Eastern, Eastern, Monmouth, Yorks and Lancs.

74. BOYD, D. A. and DYKE, G. V. 1949. *Survey of maincrop potatoes,* 1948. Report on the first year's results of a survey of farm practice and yields in England and Wales.

75. BOYD, D. A. and DYKE, G. V. 1949. *Survey of maincrop potatoes,* 1949. Preliminary report on sampling for yield.

76. Dyke, G. V. and Poulton, Emily P. 1949. *Report of the Standing Sub-Committee on methods of analysis of vegetable insecticides on the world-wide collaborative analysis of pyrethrum flowers.* The statistical analysis of the results.

REVIEW

77. Healy, M. J. R. 1949. *"Mathematical Biophysics" by N. Rashevsky.* Sci. Prog., **37**, 783.

Plant Pathology Department

GENERAL PAPERS

77. Bawden, F. C. 1949. *Some implications and limitations of recent work on plant viruses.* Fourth Int. Cong. Microbiol., p. 59.
78. ——— 1949. *Some factors affecting the susceptibility of plants to viruses.* Proc. Fifth Int. Cong. Compar. Path.
79. ——— 1949. *Research on plant viruses and virus diseases.* Brit. Agric. Bull., **2**, 347.
80. Broadbent, L. 1949. *Potatoes and weather.* Q. J. Roy. Met. Soc., **75**, 302.
81. Glynne, Mary D. 1948. *Lodging of cereal crops.* Farming, **2**, 323.
82. ——— 1949. *Check take-all and eyespot.* Farmer and Stockbreeder, p. 2283.
83. Hull, R. 1949. *The control of virus yellows in sugar beet and mangold seed crops.* Seed Trade Review, **1**, 198.
84. ——— 1949. *The relative importance of seed crops and mangold clamps as sources of beet yellows virus in Great Britain.* Proc. Int. Inst. Sugar Beet Research, XII meeting, Brussels, 1949.
85. ——— 1949. *Sugar beet yellows and the mangold crop.* J. Min. Agric., **55**, 450.
86. Gregory, P. H. 1949. *Notes on Hertfordshire fungi in* 1945, 1946 *and* 1947. Trans. Hertfordshire Natural History Soc., **23**, 54.
87. Sheffield, F. M. L. 1949. *The virus in the plant cell.* Proc. Sixth Int. Cong. Expt. Cytology.

RESEARCH PAPERS

88. Bawden, F. C. and Kassanis, B. 1950. *Some effects of host-plant nutrition on the multiplication of viruses.* Ann. Appl. Biol., **37**, 138.

The amounts of tobacco mosaic virus present in systemically infected tobacco plants varied greatly with the mineral nutrition of the plants and were related to the effects on plant growth. With plants in soil, supplements of phosphorus produced the greatest increases in plant size, in virus concentration of expressed sap, and in total virus per plant; nitrogen increased plant size only when phosphorus was also added, and only then increased virus concentration and total virus per plant. Combined supplements of phosphorus and nitrogen doubled the virus concentration of sap and increased the total virus per plant by factors up to forty. Potassium slightly reduced the virus concentration of sap, though it usually increased plant size and total virus per plant. From all plants, only about one-third of the virus contained in leaves was present in sap. Virus production seemed to occur at the expense of normal plant proteins, and the ratio of virus to other nitrogenous materials was highest in plants receiving a supplement of phosphorus but not of nitrogen.

The effects of host nutrition on the production of virus in inoculated leaves resembled those in systemically infected leaves, but were more variable.

No evidence was obtained, with plants grown in soil or sand, that host nutrition had any consistent effect on the intrinsic infectivity of tobacco mosaic virus.

The concentration of virus in sap from potato plants systemically infected with two strains of potato virus X was not consistently affected by fertilizers; the chief effect of host nutrition on virus production was indirect by altering plant size.

89. Bawden, F. C. and Kassanis, B. 1950. *Some effects of host nutrition on the susceptibility of plants to infection by certain viruses.* Ann. Appl. Biol., **37**, 46.

Fertiliser treatments that greatly influenced the growth of tobacco and potato plants in pots had little effect on the number that became infected with potato virus Y when the plants were colonised by equal numbers of infective

aphids, though the number was slightly decreased by nitrogen and increased by phosphorus.

The number of local lesions produced on leaves of tobacco and *Nicotiana glutinosa* by tomato aucuba mosaic and tobacco mosaic viruses was increased by additions of both nitrogen and phosphorus, provided that these also increased growth. The predominant effect of both nutrients in increasing susceptibility was indirect by increasing plant size, but over certain critical ranges both elements also increased the numbers of lesions produced per unit leaf area. Conditions of maximum susceptibility approximated closely to those producing optimal growth, and susceptibility, whether measured by lesions per half leaf or per unit area, was decreased by a deficiency or excess of either element. Sometimes the addition of nitrogen reduced susceptibility when still increasing plant growth.

90. Bawden, F. C. and (van der Want, J. P. H.). 1949. *Bean stipple-streak caused by a tobacco necrosis virus.* Tijdschrift over Plantenziekten, **55,** 142.

Stipple-streak of French bean, a serious disease in some parts of the Netherlands, is caused by a strain of the Rothamsted tobacco necrosis virus. The two viruses are serologically related, crystallize in the same manner and have particles of similar sizes, but differ in the manner in which they affect beans. The Rothamsted virus rarely spreads beyond inoculated leaves, whereas the stipple-streak virus does. Stipple-streak virus can also invade stems and leaves when introduced into roots.

91. Bawden, F. C., Kassanis, B. and Nixon, H. L. 1950. *The mechanical transmission and some properties of potato paracrinkle virus.* J. Gen. Microbiol., **4,** 210.

With the aid of abrasives, paracrinkle virus, hitherto transmitted only by grafting, was transmitted to Arran Victory potatoes by inoculation with sap from infected plants, either symptomless King Edward or diseased Arran Victory. The proportion of plants that became infected was increased when they were kept in darkness for some days before inoculation.

Tomato plants were more readily infected than Arran Victory potatoes, no abrasive being needed. Infected tomatoes were symptomless, but electron microscopy showed their sap to contain rod-shaped particles of variable lengths and about 10 mμ wide. Such particles have not been found in uninfected tomatoes and they are presumed to be the virus; they were destroyed by heating at 60°C.

The nature of similar particles in King Edward and Arran Victory potatoes with paracrinkle is uncertain, because rod-shaped particles were also found in uninfected Arran Victory. Rod-shaped particles also occurred in uninfected plants of all other potato varieties examined and in newly raised potato seedlings; they were not transmitted, either by inoculation or by grafting, to tomato or other hosts tested, and they withstood heating to 98°C.

These results with paracrinkle parallel those with certain other plant viruses. They invalidate theories that postulate its origin as a consequence of grafting and render unnecessary the concept that it is intrinsic to King Edward potatoes.

92. Broadbent, L. 1949. *The grouping and overwintering of* Myzus persicæ *Sulz. on Prunus species.* Ann. Appl. Biol., **36,** 334.

The aphid *Myzus persicæ* Sulz. overwintered successfully on an almond-peach hybrid for three consecutive years. Experiments provided no evidence in favour of the theory that the olfactory sense is used by aphids to find their host, nor were flying aphids attracted to other *M. persicæ* or to honeydew on the host. Having found their host, presumably by chance, alate gynoparæ tended to associate in groups.

93. Broadbent, L. 1950. *The correlation of aphid numbers with the spread of leaf roll and rugose mosaic in potato crops.* Ann. Appl. Biol. **37,** 58.

An analysis of the results of experiments in different parts of England and Wales from 1941-1947 on the spread of potato leaf roll and rugose mosaic showed that leaf roll spread was correlated with the number of alate *Myzus persicæ* (Sulzer) caught on sticky traps throughout the potato-growing season; there was some correlation with the maximum count of *M. persicæ* per 100 leaves, but this possibly results from the correlation between trapped aphids and the number per 100 leaves. Spread of rugose mosaic (potato

virus Y) was correlated to a lesser degree with number of *M. persicæ*, perhaps because other aphids species are often vectors. With both diseases higher correlations were obtained when the infected plants were dispersed among the healthy crop than when they were placed together in a row. It is concluded that it is possible to predict the average health of potato stocks in the following year from average trap data; further work may enable the health of individual stocks to be predicted.

94. Broadbent, L., Cornford, C. E., Hull, R. and Tinsley, T. W.1950. *Overwintering of aphids, especially* Myzus persicæ *Sulz. in root clamps.* Ann. Appl. Biol., **36**. 513.

Mangold clamps in many districts of the British Isles were found to provide overwintering sites for *Myzus persicæ* (Sulz.), *Hyperomyzus staphyleæ* (Koch) and *Aulacorthum solani* (Kalt). After a severe winter, when other means of overwintering are few, clamps may be the most important source of *M. persicæ*. Only *M. ascalonicus* Doncaster was found in swede clamps.

Factors affecting the infestation of clamped mangolds by *M. persicæ* were the number of aphids on the crop when lifted, the methods of topping and clamping the roots, and the temperature in the clamp. *M. persicæ* was introduced on the leaves, and close topping was often an efficient means of control. Close topping did not control *H. staphyleæ*; normally, this aphid does not seem to be a root-feeding species, but with artificially colonized mangolds it fed on both exposed roots and foliage. It is not known how this species enters the clamps. The temperature in clamps was influenced by that of the outside air and the type of cover, but changes were long-term and did not reflect diurnal variations in external air temperature. Straw, covered with soil, was the best form of cover.

In addition to harbouring *M. persicæ*, mangold clamps are also important sources of sugar-beet yellows virus.

95. Capoor, S. P. 1949. *The movement of tobacco mosaic viruses and potato virus* X *through tomato plants.* Ann. Appl. Biol., **36**, 307.

Tomato aucuba mosaic virus, tobacco mosaic virus and potato virus X took 3·5–4, 5 and 3 days respectively to move from inoculated tomato leaflets into the petioles and stems.

On reaching the stem each virus usually first moved downward, but in some plants both upward and downward movement occurred simultaneously and in a few upward movement occurred first.

All three viruses travelled through the stem at approximately the same rate. Each was capable of travelling more than 80 cm. during the first 12 hr. after entering the stem, giving a minimal average rate of about 8 cm. per hr.

Uninfected pieces of stem invariably occurred between infected pieces. Maximum length of stem through which virus particles had apparently passed without causing infection, were 44·5, 49 and 39 cm. for the three viruses.

96. Chaudhuri, R. P. 1950. *Studies on two aphid-transmitted viruses by leguminous crops.* Ann. Appl. Biol. (In the press.).

Pea mosaic virus was transmitted by *Myzus persicæ* Sulz., *Macrosiphum pisi* Kalt., *M. solanifolii* Ash. and *Aphis fabæ* Scop., but not by *Hyperomyzus staphyleæ* Koch. It is a 'non-persistent' virus (Watson and Roberts 1939) and is most readily transmitted when vectors are fasted and then given a short infection-feeding. Vector efficiency was not increased by increase in preliminary fasting beyond 15 min. or with increasing infection-feeding beyond one hour. Most aphids became non-infective within 15 min. when feeding, but fasting aphids remained infective for 3 hr. Species that fed readily on the infected plants were less efficient vectors than those which did not. Seed set by infected plants produced healthy seedlings.

Pea enation mosaic virus persisted in *M. persicæ and M. pisi* for more than 140 hr.; its transmission was unaffected by preliminary treatments of aphids. No transmission was obtained until at least 4 hr. after aphids had left infected plants; usually the 'latent' period exceeded one day and its duration was apparently unaffected by the length of the infection-feeding.

97. Glynne, Mary D. and Moore, F. Joan. 1949. *Effect of previous crops on the incidence of eyespot on winter wheat.* Ann. Appl. Biol., **36**, 341.

Surveys of winter wheat from 1939 to 1946 show that eyespot (*Cercosporella herpotrichoides* Fron.) occurs throughout Britain and that its incidence depends largely on previous cropping and on weather. Examination of 551

crops on land whose cropping for the previous 4 years was known showed that the incidence rose steadily with increasing numbers of preceding wheat and barley crops; where neither crop had been taken for 4 years the proportion of crops with more than 70 per cent. infected straws as 2 per cent., rising to 45 per cent. where three or four such crops had been taken and the average straws infected rose from 6 to 55 per cent.

The percentage infection to be expected in various groups of crops was calculated from previous cropping; it was compared with the actual infection and so used to assess the importance of other factors in determining the incidence of eyespot. High spring rainfall, early sowing and a dense plant increased incidence and low spring rainfall, late sowing and a thin plant reduced it.

Eyespot was not usually severe on newly ploughed grassland until the third or fourth crop of wheat, but under very wet conditions it was sometimes severe in the second crop.

Oats is much less susceptible than wheat or barley, but some crops were found with a third of their straws infected.

A brief survey of winter wheat in Holland suggested possible causes for the rise and fall of eyespot in recent years and for its present lower incidence there as compared with East Anglia.

98. Gregory, P. H., (Peace, T. R. and Waller, S.) 1949. *Death of sycamore trees associated with an unidentified fungus.* Nature, **164,** 275.

A description is given of what appears to be a lethal disease of sycamore (*Acer pseudoplatanus* L.). It is caused by an unidentified fungus which stains the heartwood and ultimately produces large numbers of dry spores in the bark. About 200 trees in a small area in Essex have been killed.

99. Kassanis, B. 1949. *Potato tubers freed from leaf-roll virus by heat.* Nature, **164,** 881.

All potato tubers infected with leaf-roll virus that survived 25 or more days at 37·5°C. produced healthy plants; when heated for periods of between ten and twenty days some produced healthy and others infected plants. Treatment for 40 days did not free plants from potato virus X.

100. Kleczkowski, A. 1950. *Interpreting relationships between the concentrations of plant viruses and numbers of local lesions.* J. Gen. Microbiol., **4,** 53.

The effect of dilution on numbers of local lesions produced by plant viruses was tested graphically and statistically for compatibility with contrasting hypotheses. Experimental results are incompatible with the hypothesis that lesions are produced because of chance encounters between single virus particles and susceptible regions of a uniform type, and that variations in response to similar inoculation between different leaves or plants occur solely because of variations in numbers of such regions. The results are compatible with the hypothesis that individual susceptible regions vary in susceptibility so that different numbers of virus particles are needed to produce a lesion, (variations being such that logarithms of minimal effective doses are normally distributed). The second hypothesis is, therefore, more probably correct, but the first can be fitted to experimental results by introducing various auxiliary assumptions, such as the existence of qualitatively different virus particles and susceptible regions. Conclusive evidence is unlikely to come from mathematical treatment of existing results, but only from a new experimental approach.

101. Kleczkowski, A. and Nixon, H. L. 1950. *An electron microscope study of potato virus x in different states of aggregation.* J. Gen. Microbiol., **4,** 220.

Electron micrographs of potato virus X show tenous rod-shaped particles of variable length but constant width of about 10mμ. Lightly shadowed rods lying along the direction of shadowing show a regular cross banding at intervals of about 10 mμ. Attempts to purify the virus cause the particles to aggregate and become entwined to form extensive rope and netlike structures. This aggregation may be responsible for the loss of solubility that often accompanies purification, though similar structures are visible in micrographs of both soluble and insoluble preparations of the purified virus. Hydrolysis by chymotrypsin produces products too small to be resolvable, and the material remaining after most of a preparation has been hydrolysed appears similar to that in unincubated preparations.

102. WATSON, M. A. 1949. *Some notes on plant virus diseases in South Australia.* J. Austr. Inst. Agric. Sci., **15**, 76.

Viruses collected in Adelaide, South Australia, from Nemesia and Petunia were provisionally identified as cucumber virus 1, and tobacco ringspot virus respectively. A virus from subterranean clover, (*Trifolium subterraneum*) was identified with the " sub-clover virus " described by Aitken and Grieve, (J. Austr. Inst. Agr. Sci. **9**, No. 2, 1943). It was not related to a virus found in garden peas, which was provisionally identified as common pea mosaic.

103. WATSON, M. A., HULL, R. and (HARTSUIJKER, K.) 1949. *Yellowing disease of " Family* 41 *" sugar beet.* Nature, **163**, 910.

The paper by Clinch and Loughnane entitled " Seed transmission of virus yellows of sugar beet " is misleading because it suggests that beet yellows virus is seed transmitted, and there is much evidence to show that it is not. The yellowing disease found in a breeder's pure line of sugar beet, Family 41, resembles yellows in some respects, and there is some evidence that it is caused by an aphid-transmitted virus, but this does not appear to be a strain of beet yellows virus.

Biochemistry Department

104. (BOWES, J. H.) and KENTEN, R. H. 1948. *The amino acid composition and titration curve of collagen.* Biochem. J. **43**, 358–365.

105. (BOWES, J. H.) and KENTEN, R. H. 1948. *The effect of alkalis on collagen.* Biochem. J. **43**, 365–372.

106. (BOWES, J. H.) and KENTEN, R. H. 1949. *The effect of deamination and esterification on the reactivity of collagen.* Biochem. J. **44**, 142–152.

107. (BOWES, J. H.) and KENTEN, R. H. 1949. *Some observations on the amino acid distribution of collagen, elastin, and reticular tissue from different sources.* Biochem. J. **45**, 281–285.

108. (BOWES, J. H.) and KENTEN, R. H. 1950. *The swelling of collagen in alkaline solutions* 1. *Swelling in solutions of sodium hydroxide.* Biochem. J. **46**. (in the press).

109. HEINTZE, S. G. and MANN, P. J. G. 1949. *Studies on soil manganese.* 1. *Pyrophosphate as extractant of soil manganese.* 2. *The exchange properties of the manganese of neutral and alkaline organic soils.* J. Agric. Sci. **39**, 80–95.

1. The presence and distribution of divalent and trivalent manganese in pyrophosphate extracts of mineral and highly organic soils were studied.

2. A method for estimating divalent manganese in neutral pyrophosphate solutions was developed form the dismutation reaction

$$2Mn^{+++} + 2H_2O = Mn^{++} + MnO_2 + 4H^+.$$

3. By means of this reaction it was possible to show that the manganese of pyrophosphate extracts at pH 9·4 of mineral soils of low organic matter content was in the divalent form.

4. The reverse dismutation reaction may occur during extraction of soils with neutral pyrophosphate solution. The presence of trivalent manganese in such extracts cannot therefore be taken as proof of the existence of trivalent manganese in the soils. Nor, since pyrophosphate extracts of organic soils reduce manganese dioxide and the manganese higher oxides of manganese in soils, can the presence of divalent manganese in these extracts be taken as proof of the existence of divalent manganese in the organic soils.

5. The use of the reverse dismutation reaction to investigate the nature of manganese higher oxides in soils is restricted to mineral soils low in organic matter. Organic soils retain part of the divalent manganese added in pyrophosphate at pH 7 in a form not readily exchangeable with NH_4^+ Ca^{++} or other polyvalent cations. The manganese so held can, however, be recovered by extraction with pyrophosphate at pH 9·4.

6. Only a small part of the manganese taken up by organic soils in the presence of ammonium acetate could be recovered by subsequent repeated extractions with ammonium acetate. The recovery was markedly increased by the addition of low concentrations of copper, cadmium, nickel or zinc salts to the M-ammonium acetate.

M

With these salt mixtures considerably higher figures were also obtained for the exchangeable manganese of soils to which no manganese has been added than with M-ammonium acetate alone. Where copper sulphate was added the additional manganese may have been liberated by reduction of the higher oxides of manganese.

7. In attempting to extract metal organic complexes three main fractions of organic matter were obtained ; the first being water-soluble after extracting the soil with solium chloride, the second being soluble in pyrophosphate, and the third in 2 per cent. sodium hydroxide. Manganese or copper added as sulphate during the sodium chloride extraction and retained in a form not exchangeable with Na ions was recovered in the subsequent water and pyrophosphate extracts. Evidence was obtained that in the water extracts the manganese and copper were still combined with the organic matter, apparently in the form in which they were originally present in the soil.

8. The hypothesis is advanced that part of the manganese of neutral and alkaline organic soils is present as complexes with the organic matter. Conditions under which the combination of the soil manganese in such complexes could cause manganese deficiency in the plant are discussed.

110. Kenten, R. H. and Mann, P. J. G. 1949. *The oxidation of manganese by plant extracts in the presence of* H_2O_2. Biochem. J. **45**, 255–263.

1. A system which oxidizes manganese in the presence of hydrogen peroxide has been demonstrated in horse-radish root extracts. This system also exists in other root extracts.

2. Under suitable conditions (*i.e.* in pyrophosphate or citrate at pH 7) the oxidation product accumulates as a coloured manganic complex. Using horse-radish root extract, manganese dioxide was isolated by the dismutation of manganipyrophosphate at weakly alkaline reaction. The oxidation product decomposes hydrazine and can be estimated manometrically by means of this reaction.

3. An increase in the rate of decomposition of hydrogen peroxide was observed on adding small amounts of manganous sulphate to horseradish extracts. This effect was attributed to manganese oxidation.

4. The manganese oxidising system in horseradish extract consists of a thermolabile and a thermostable factor together with hydrogen peroxide. Partially purified peroxidase preparations in the presence of certain peroxidase substrates and hydrogen peroxide, oxidize Mn++. It is suggested that the thermolabile and thermostable factors in the extract are peroxidase and peroxidase substrate respectively.

5. The hypothesis is advanced that the manganese reduces the oxidized peroxidase substrate and thereby is itself oxidized. This involves the substrate in a cycle of oxidation and reduction. At low hydrogen peroxide concentrations, the manganese oxidation product may react with plant metabolites other than hydrogen peroxide ; this would involve the manganese in an oxidation-reduction cycle, which may explain its effect on plant respiration.

111. Kenten, R. H. and Mann, P. J. G. 1950. *The oxidation of manganese by peroxidase systems.* Biochem. J., **46**. (in the press).

1. Plant peroxidase preparations from horseradish and turnip in the presence of certain phenolic substrates and H_2O_2 have been shown to oxidise manganese.

2. Oxidation of manganese could be demonstrated with phenol, p-cresol o-cresol and resorcinol, as phenolic substrate, but not with hydroquinone, catechol, pyrogallol and caffeic acid.

3. The effect of variation in the peroxidase, phenolic substrate, and H_2O_2 concentrations have been studied. An active system could be demonstrated with 1μg of p-cresol.

4. The results are in agreement with the hypothesis previously advanced that the manganese reduces an oxidation product of the phenolic substrate and thereby is itself oxidised.

112. Mann, P. J. G. 1950. *Manganese and plant metabolism.* Spec. Conf. in Agriculture, Australia, 1949.

113. Paterson, J. S. and Pirie, N. W. 1949. *The chemical and biological properties of antigenic fractions from* Brucella abortus. Proc. Fourth Int. Cong. Microbiol. p.234.

114. Pirie, N. W. 1949. *Introductory article to the symposium "Nature of the bacterial surface."* Edited by A. A. Miles and N. W. Pirie.

115. Pirie, N. W. 1949. *The association of viruses with other materials in the cell and in extracts.* Proc. Sixth Int. Cong. Expt. Cytology, 1947. Expt. Cell. Res. Suppl. L., 183–191.

116. Pirie, N. W. 1949. *Structure and activities of the bacterial surface.* Nature, **163,** 897.

117. Elsden, S. R. and Pirie, N. W. 1949. *Obituary Notice—Marjorie Stephenson.* J. Gen. Microbiol., **3,** 329.

Nematology Department

119. Fenwick, D. W. *Viability studies on the potato-root eelworm* Heterodera rostochiensis. *1. The estimation of total cyst content.* Accepted for publication by J. Helminthology.

The general principles underlying the estimation of cyst contents are discussed and a final technique to this end described. Attention is paid to the selection of a representative sample from a mass of cysts, the treatment of cysts prior to dissection, the method of dissection and enumeration of eggs and larvæ obtained. The paper is followed by an appendix by Miss E. Reid on an improved method of cyst dissection.

120. Fenwick, D. W. 1949. *Investigations on the emergence of larvæ from cysts of the potato-root eelworm* Heterodera rostochiensis. *1. Technique and variability.* J. Helminthology, **23,** 157-170.

Data obtained by hatching 750 individual cysts in potato-root diffusate are presented. The variation exhibited by these cysts is estimated and the effect of different methods of analysis described. It is concluded that except for very special purposes single cyst hatching is not an economical use of time and the use of multiple samples of at least 100 cysts is advocated.

121. Fenwick, D. W. 1950. *Investigations on the emergence of larvæ from cysts of the potato-root eelworm* Heterodera rostochiensis. *2. The form of hatching curve.* J. Helminthology, **24,** 75-86.

Individual cysts as well as groups of 100 cysts were exposed to the action of potato-root diffusate and the number of larvæ liberated at the end of certain intervals of time recorded. The sigmoid nature of the hatching curve when plotted against log-time was established. The implications of this are discussed. It is concluded that probit analysis of hatching data in conjunction with the total number of larvæ liberated is sufficient to enable comparisons to be made between different sets of hatching data.

122. Fenwick, D. W. 1950. *Investigations on the emergence of larvæ from cysts of the potato-root eelworm* Heterodera rostochiensis. *3. Larval emergence in soil under the influence of potato-root diffusate.* J. Helminthology, **24,** 15-86.

The effect of leachings from three varieties of potato plants on three soils naturally infested with *Heterodera rostochiensis* was investigated. Soil leachings alone resulted in a 50 per cent. hatch whilst leachings from growing plants caused 86 per cent. of the larvæ to emerge. Significant differences were detected between soils and there was evidence of differences in degree of emergence due to leachings from different host varieties.

123. Fenwick, D. W. 1950. *"Buried bag" technique for testing 'D-D' as a soil fumigant against the potato-root eelworm.* Nature, **165,** 694.

Pot experiments were carried out on the effect of D-D on *Heterodera* cysts. It was found that mortality induced in cysts enclosed in bags which were buried in the pots of soil was very much higher than that induced in cysts occurring naturally in the soil. The need for caution in interpreting such results is stressed.

124. Fenwick, D. W. *Varying nematocidal effects of different samples of D-D against the potato-root eelworm* Heterodera rostochiensis. Accepted for publication by J. Helminthology.

Four samples of D-D were investigated for their nematocidal effect against *Heterodera rostochiensis*. Five dosages of D-D were investigated together with

one control. Probit curves were plotted for each sample and the probable dosage of each sample needed to give different kills was computed. Significant differences in dosage were needed to give 95 and 99 per cent. kills ; nearly seven times as much of one sample as of another was required to give a 99 per cent. kill.

125. Fenwick, D. W. and Franklin, M. T. *Further studies on the identification of* Heterodera *species by larval length.* Accepted for publication by J. Helminthology.

Using a standard technique described in a previous paper, larvæ were measured from cysts of eight populations of *Heterodera* from known host plants. The data thus obtained were analsyed and parameters derived for the mean lengths and standard deviations for each population. Methods of identifying populations by means of these parameters are described.

An appendix by Mr. G. V. Dyke is concerned with the theory of statistical analysis used in this paper.

126. Franklin, Mary T. 1949. *A quick method of demonstrating nematodes of the genus* Aphelenchoides *in leaves.* J. Helminth. **23** (1/2), 91–93.

By this method nematodes of the genus *Aphelenchoides* parasitic in leaves can be stained *in situ*. Infested leaves are plunged, without previous preparation, into boiling lactophenol containing 0·1–0·5 per cent. acid fuchsin for about five minutes. The leaves are left in the lactophenol while it cools, differentiated in 50 per cent. alcohol and then transferred to concentrated phenol where they are cleared until the worms can be seen stained red in the unstained leaf tissue.

127. Franklin, Mary T. 1950. *Two species of* Aphelenchoides *associated with strawberry bud disease in Britain.* Ann. Appl. Biol. **37**, 1–10.

Two species of *Aphelenchoides* have been recognised in the buds of eelworm-diseased strawberry plants. They are identified as *A. fragariæ* (Ritzema-Bos 1891) and *A. ritzema-bosi* (Schwartz 1911). The chief diagnostic characters are described and reasons given for regarding *A. olesistus* (Ritzems-Bos 1893) as a synonym of *A. fragariæ* (Ritzema-Bos 1891). A suggestion is made that *A. ribes*, the blackcurrant eelworm, may be synonymous with the strawberry eelworm, *A. ritzema-bosi*, owing to their morphological similarity and to the successful transfer, in inoculation experiments, of each to the normal host of the other.

128. Franklin, Mary T. 1950. *The cyst-forming species of the genus* Heterodera *Schmidt* 1871. Technical Communication No. 1 of the Commonwealth Bureau of Agricultural Parasitology (in press).

This is a review of the published work on the 8 cyst-forming species and two varieties of *Heterodera*. The morphology, bionomics, effects on the host plants, host ranges and distribution are dealt with, and brief accounts are given of some of the more recent work on control. There is a bibliography of references to work published up to the end of 1948.

129. Franklin, Mary T. and Goodey, J. Basil. 1949. *A cotton blue-lactophenol technique for mounting plant-parasitic nematodes.* J. Helminthology **23**, 175-178.

A method is described by which small nematodes such as species of *Aphelenchoides, Ditylenchus, Monochus* and *Dorylaimus* may be brought rapidly from fixative to lactophenol containing ·01 per cent. cotton blue, in which they are stained. They can then be transferred to and permanently mounted in slightly tinted lactophenol. The method depends on the temperature of the first lactophenol being between 60° and 80°C., if it is lower the worms will collapse. The whole process can be accomplished in a matter of minutes compared with the weeks usually required for processing in glycerine.

130. Goodey, J. Basil. 1949. *The control of* Anguillulina dipsaci *on the seed of teazel and red clover by fumigation with methyl bromide.* J. Helminthology, **23**, 131-174.

It is shown that infested seed of both teazel and red clover can be successfully treated with methyl bromide using the method devised by T. Goodey in 1945 for onion seed. The germination of both teazel and red clover was slightly improved by fumigation which also controlled fungi and bacteria very well. It is reported that eelworm disease of teazel was first discovered in England by Staniland and Miss Britton in 1948 and that of 503 samples of red clover seed examined by T. Goodey in 1944 about 6 per cent yielded specimens of *A. dipsaci*.

131. Goodey, J. Basil. 1950. *The "Hemizonid", a hitherto unrecorded structure of members of the Tylenchoidea.* (Ready for press).

132. Goodey, J. Basil. 1950. *The potato tuber-rot nematode,* Ditylenchus destructor *Thorne,* 1945, *the cause of eelworm disease in bulbous iris.* (Ready for press).

133. Goodey, T. and Goodey, J. Basil. 1949. *Tuber-rot eelworm of potato and its weed hosts.* J. Helminth. **23,** 89–90.

It was found in Prince Edward Island that the potato tuber-rot eelworm *Ditylenchus destructor,* can cause lesions on the underground stems of Corn Mint, *Mentha arvensis* L. The authors confirm the occurrence of lesions on Corn Mint rhizomes in fields in the Fens where in 1947 potato tubers had been severely infested with this eelworm. They were able to find *D. destructor* in these lesions and in similar ones on the rhizomes of another common weed, Corn Sowthistle, *Sonchus arvensis* L. Both weeds were abundant in wheat and barley stubble in late August, 1948 and it is clear that they can serve as alternative hosts on which the parasite can perpetuate itself in the absence of potatoes.

134. Goodey, T. 1949. *Laboratory methods for work with plant and soil nematodes.* Min. Agric. and Fish. Tech. Bull. No. 2. H.M.S.O.

A number of laboratory methods and techniques are described and illustrated suitable for collecting, processing, staining and mounting plant and soil nematodes.

135. Goodey, T. 1950. *Soil and fresh water nematodes.* (In the press).

136. Peters, B. G. 1949. *Potato root eelworm, D-D, and soil sterilization. III. Results for* 1947. J. Helminth., **23,** 73–88.

A factorial pot experiment to test the effects on potatoes of steam sterilization of soil, infestation with *Heterodera rostochiensis* cysts ; and injection of D-D (applied in that order) was repeated in the second year, with the addition of mixed fertilizers as a fourth factor. The first-year findings were reversed in that the infestation had a significant negative effect, and that the positive effects of steam sterilization and the "soil amendment" action of D-D did not re-appear. In addition to the positive fertilizer effect, a negative (fertilizer x eelworm) interaction occurred ; this was interpreted as a wastage, some of the fertilizer being used in effect for the production of eelworm cysts.

137. Peters, B. G. and Fenwick, D. W. 1949. *Field trials with D-D mixture against potato-root eelworm.* Ann. Appl. Biol. **36,** 364–382.

D-D mixture was used against *Heterodera rostochiensis* at seven 2-acre sites on sands, silts and blackland soils. Apart from a pilot trial where soil was injected in spring, injections were carried out in the autumn, and potatoes were grown the following year. Factors investigated were rate of application (0, 200, 400 and 800 lb. D-D/acre), depth of injection (4 or 8 in.) and the effect of rolling after injection. At the most responsive of the sites (Wainfleet), increases in yield, kill, and the post-crop eelworm population were all roughly proportional to the rate of application. Under favourable circumstances a 50 per cent. in yield and something like a 50 per cent. reduction in eelworm population 4 weeks after injection can be expected from 800 lb./acre, but the reduction is more than made good during the growth of the subsequent crop ; accelerated multiplication of eelworm on the treated plots leads to their having a larger population than the untreated controls at lifting time. Of the sites tested, the blackland soils gave a lower eelworm kill and a much lower yield increase from D-D than silts or sands. After autumn injection the nematocidal, and probably the phytocidal effects of D-D persist in the soil for many weeks. After spring injection a taint was detectable in the crop, with a chemical correlate in the form of some unknown, fixed chlorine compound.

138. Peters, B. G. 1949. *Potato root eelworm a serious and easily-spread pest. Control measures discussed.* Ann. J. R. Lancs. Agric. Soc., Year 1949, 23–27.

139. Peters, B. G. 1949. *Control of plant nematodes.* Rep. Progr. Appl. Chem., **33,** 479–480.

140. Peters, B. G. 1948. *Final report on trials with D-D against potato eelworm* (Heterodera rostochiensis). Confidential report to the Agricultural Research Council, 36 pp.

Entomology Department

BOOK

141. Barnes, H. F. 1949. *Gall midges of economic importance.* Vol. 6. *Gall midges of miscellaneous crops.* Crosby Lockwood and Son, Ltd.

The sixth volume of the series deals with the gall midges injurious to Bamboos, Basket Willows, Beverage Plants, Dye and Textile Plants, Herbs (Aromatic, Culinary and Medicinal) Insecticide plants, Spices and Sugar plants.

PUBLICATIONS

142. Barnes, H. F. 1949. *The slugs in our gardens.* New Biology, **6,** 29–49.

A popular account of the ecology of slugs.

143. ——— 1949. *The control of slugs on allotments and gardens.* The Northern Allotment and Garden, **1,** 99–102, 125–128, 153–156.

144. ——— 1949. *Slugs.* Wye, **1,** 50–53.

A precis of the above.

145. Evans, A. C. 1948. *On some earthworms from Iowa, including a description of a new species.* Ann. Mag. Nat. Hist. (II) **14,** 514.

146. Evans, A. C. 1948. *A method of studying the burrowing activities of earthworms.* Ann. Mag. Nat. Hist., (II) **14,** 643.

147. Evans, A. C. 1948. *The identity of earthworms stored by moles.* Proc. Zool. Soc. London. **118,** (2), 356–359.

148. Evans, A. C. 1948. *Studies on the relationships between earthworms and soil fertility.* II. *Some effects of earthworms on soil structure.* Ann. Appl. Biol., **35,** (1), 1–13.

149. Evans, A. C. and Guild, W. J. McL. 1948. *On the cocoons of some British Lumbricidæ.* Ann. Mag. Nat. Hist., (II) 14, 714.

150. Evans, A. C. and Guild, W. J. McL. 1948. *Some notes on reproduction in British earthworms.* Ann. Mag. Nat. Hist., (II) **14,** 654.

151. Evans, A. C. and Guild, W. J. McL. 1948. *Studies in the relationships between earthworms and soil fertility.* IV. *On the life cycles of some British lumbricidæ.* Ann. Appl. Biol., **35,** (4), 471–484.

152. Evans, A. C. and Guild, W. J. McL. 1948. *Studies in the relationships between earthworms and soil fertility.* V. *Field populations.* Ann. Appl. Biol., **35** (4), 485–493.

153. Guild, W. J. McL. 1948. *Studies on the relationships between earthworms and soil fertility.* III. *The effect of soil type on the structure of earthworm populations.* Ann. Appl. Biol., **35,** (2), 181–192.

154. Johnson, C. G. 1949. *Development of research in the insect aerofauna.* Brit. Sci. News. **2,** 243-246.

The development of research on insect aerobiology during the last 50 years is described along with special problems now being investigated at Rothamsted and Cardington.

155. ——— 1950. *The infestation of a bean field by* Aphis fabæ *Scop. in relation to wind direction.* Ann. Appl. Biol. (In the press).

The primary migration of the bean aphis from winter hosts to beans was studied in relation to wind direction. The infestation of the bean crop was heaviest along the edges facing the prevailing wind during primary migration. Other factors in addition to wind direction which may have influenced the infestation pattern are dicsussed.

156. ———1950. *A suction trap for small airborne insects which automatically segregates the catch into successive hourly samples.* Ann. Appl. Biol. **37,** 80-91.

A new trap has been developed—namely the suction trap—to overcome objections to existing methods of trapping aphids and other small insects. The apparatus which is described here has a device for separating up the daily catch in 24 successive hourly samples.

157. ——— 1950. *The comparison of suction trap, sticky trap and tow-net for the quantitative sampling of small airborne insects.* Ann. Appl. Biol. (In the press).

The performances of suction trap, sticky trap and tow-net are compared. At low wind-speeds the sticky trap and tow-net are very inefficient ; at higher wind-speeds they suffer from the defect of obtaining samples with a variable and unknown degree of weighting due to simultaneous variation

of wind-speed and insect density. The suction trap which samples air at a constant rate in all wind-speeds appears to give more accurate results.

158. JOHNSON, C. G. and EASTOP. V. F. 1950. *Aphids captured in a Rothamsted suction trap five feet above ground level from June to November, 1947.* Proc. Roy. Ent. Soc. (In the press).

159. JOHNSON, C. G. and SOUTHWOOD, T. R. 1949. *Seasonal records in* 1947 *and* 1948 *of flying* Hemiptera Heteroptera, *particularly* Lygus pratensis *caught in nets* 50 *ft. to* 3,000 *ft. above the ground.* Proc. Roy. Ent. Soc. London. A. **24** (10–12), 128–130.

160. TAYLOR, L. R. 1950. *Synchronous movements of bean aphis.* Ent. Mon. Mag., **84**, 52.

161. WILLIAMS, C. B. 1949. *Jaccard's generic coefficient and coefficient of floral community in relation to the logarithmic series.* Ann. Bot. N.S. **13** (9), 53–58.

A discussion of the validity of Jaccard's Coefficients suggesting that they are both influenced by the size of the sample as well as by the Diversity of the population.

162. ——— 1949. *Migration in lepidoptera and the problem of orientation.* Proc. Roy. Ent. Soc. London. C. **13**, 70–84.

A survey of evidence showing that the direction of the wind is not likely to be the determining cause in the orientation of migratory flights in lepidoptera.

163. ——— 1949. *An attempt to forecast changes in insect populations.* British Sci. News, **2**, 360–362.

A brief account of the work done on this problem at Rothamsted, particularly designed for oversea readers and press.

165. ——— (1950). *The application of the logarithmic series to the frequency of occurrence of plant species in quadrats.* J. Ecol., **37**, 1-30.

A discussion of the frequency distribution of plant species in quadrats showing that if the plants are distributed in a log-series—or in any frequency which gives a straight line relation between the number of species and the log. of the number of quadrats (*i.e.* area sampled)—then the distribution of species depends on the size of the quadrats and on a measure of Diversity. Since the size of the quadrat is purely a matter of selection by the observer—the real ecological factor which is being measured is the Diversity.

Bee Department

166. BUTLER, C. G. 1949. *Some trends in bee research today.* Ann. Rpt. Cent. Assoc. British Beekeepers' Association.

167. RIBBANDS, C. R. 1949. *The effect of anaesthetics upon the foraging behaviour of the honeybee.* (Ready for press).

Anaesthesia with chloroform does not impair the memory, change the foraging behaviour or reduce the longevity of worker honeybees. Although anaesthesia with carbon dioxide does not impair the memory of treated bees it effects their foraging activities and results in the elimination or reduction of their pollen collecting tendencies, but has no direct effect upon their longevity. Treatment of newly emerged bees with carbon dioxide eliminates most of their brood-rearing and wax-secreting activities and causes them to forage at an early age.

The effects of anaesthesia with nitrogen are similar to those with carbon dioxide and both would appear to exert their effects by causing a temporary oxygen lack.

168. SIMPSON, J. 1949. *Humidity in the winter cluster of a colony of honeybees.* (Ready for press).

Outside weather conditions have little effect on the humidity within a winter cluster at moderate winter temperatures. High external humidities can only affect the colony by causing water vapour discharged from the cluster to condense within the hive.

The atmosphere in a cluster containing brood has a lower saturation deficiency than that found in the same cluster without brood. The absolute humidity of the atmosphere varies from point to point in the cluster, and in general follows the temperature in such a way that throughout much of the cluster the saturation deficiency only varies within small limits.

BOOK

169. Butler C. G. 1949. *The Honeybee. An Introduction to her Sense-Physiology and Behaviour.* Oxford University Press.

Insecticides Department

GENERAL PAPERS

170. Potter, C. 1948. *Modern insecticides and methods of application.* J. Roy. Agric. Soc., **109,** 175–193.

171. Tattersfield, F. 1948. *Early experiments on Pyrethrum growing in England.* Pyrethrum Post, **1,** No. 1, 3–8.

172. Potter, C. 1948. *The development of pyrethrum-oil sprays for the control of Insect pests of stored products.* Pyrethrum Post, **1.** No. 2, 5-7.

173. Way, M. J. *Insects and insecticides.* Chem. and Druggist. September and October, 1948.

RESEARCH PAPERS

174. McIntosh, A. H. 1949. *Relation between particle size and shape of insecticidal suspensions and their contact toxicity.* II. *DDT and rotenone suspensions against* Oryzaephilus surinamensis *L. with some time mortality studies.* Ann. Appl. Biol., **36,** 535.

DDT. suspensions previously tested on adult *Tribolium castaneum* Hbst. (Part I.) were tested on *Oryzaephilus surinamensis* L. and gave similar results. *i.e.* toxicity increases with increase in size of crystals in suspension within the limits tested. No tests were made on the effect of crystal shape on toxicity, nor of the effect of time on mortality.

Five types of rotenone suspension were prepared :—(1) Colloidal rotenone. (2) Small elongated plate shaped crystals. (3) Small hexagonal plates in aggregates. (4) and (5) Two suspensions containing hexagonal plate shaped crystals of different sizes. The toxicity of these suspensions to adult *O. surinamensis* L. was inversely related to particle size up to 150μ. The variation in toxicity may be 500 times. Crystal shape seems to be unimportant. It appears therefore, that results with rotenone are the opposite of those with D.D.T.

The variation of mortality with time was also studied. Crystalline rotenone like D.D.T. (Part I.) gives a gradually increasing kill ; colloidal rotenone gives an initial paralytic effect followed by recovery of the insects.

175. Lord, K. A. 1949. *The effect of insecticides on the respiration of* Oryzaephilus surinamensis *L. An attempt to compare the speed of action of a number of D.D.T. analogues.* Ann. Appl. Biol., **36,** 113–138.

A method has been devised for observing the effects of a number of non-volatile contact poisons on the oxygen uptake of groups of *Oryzæphilus surinamensis* L. Toxic concentrations of D.D.T. and of its analogues applied as dusts increase the rate of oxygen uptake ; sub-lethal concentrations appear to have no effect. The total oxygen uptake of groups of starving *O surinamensis* appears to be constant, whether or not they are treated with D.D.T. or its analogues. In each case a linear relationship appears to exist between length of life and total volume of oxygen respired before death.

The magnitude of the stimulus of D.D.T. to increase respiration appears to be independent of the concentration of the dust. The stimuli resulting from the action of D.D.T. and its analogues are approximately equal as are the rates at which the insects die. There is, however, an apparent correlation between molecular weight and length of life, i.e., there is a tendency for the insects treated with the poisons of lower molecular weight to die more rapidly than those treated with the analogues of high molecular weight. The effect of benzene hexachloride on the respiration of *O. surinamensis* has been shown to be similar to that of D.D.T. The effects of a number of insecticides may be classified into two groups (a) Those stimulating respiration *e.g.* D.D.T., B.H.C., and the pyrethins and (b) Those depressing respiration *e.g.* rotenone, and the organic thiocyanate Lethane B.71.

176. Pradhan, S. 1948. *Studies on insecticides film with special reference to the effects of temperature and humidity.* 1. *Preliminary investigations, especially on concentration-time-mortality relations.* Bull. Ent. Res. **40,** 1-25.

177. Pradhan, S. 1948. *Studies on insecticide films with special reference to the effects of temperature and humidity.* 2. *Effect of temperature on the toxicity of D.D.T. films.* Bull. Ent. Res. **40,** 239.

178. PRADHAN, S. 1948. *Studies on insecticide films with special reference to the effects of temperature and humidity.* 3. *Effect of relative humidity on the toxicity of films.* Bull. Ent. Res. **40**, 431.

179. TATTERSFIELD, F., POTTER, C., LORD, K. A., GILLHAM, E. M., WAY, M. J., and STOKER, R. I. 1949. *Insecticides derived from plants.* Kew Bulletin, No. 3.

180. WAY, M. J. 1949. *A technique for determining the Stomach Poison effect of insecticides used against leaf eating insects.* Ann. Appl. Biol. **36**, 86–112

Methods devised for feeding individual insects with leaf areas bearing known deposits of insecticides are described. An account is given of the difficulties of applying the technique to small insects and to those with erratic feeding habits. Some data is given to illustrate the effect of various factors on resistance of insects to stomach poisons. The dosage mortality curve for stomach poison effect was found to be typically sigmoid : analysis of results by the method of probits therefore proved satisfactory.

181. WAY, M. J. 1949. *Laboratory experiments on the effect of D.D.T. and B.H.C. on certain aphidophagous insects and their hosts.* Bull. Ent. Res. **40**, 279—297.

It was found that Syrphid larvæ were remarkably resistant to D.D.T. films on foliage. Adults were susceptible and even sublethal concentrations inhibited oviposition. Field concentrations of B.H.C. preparations were destructive only to young Syrphid larvæ. Adults were highly susceptible. Field strengths of D.D.T. and B.H.C. dusts and sprays on foliage were toxic to adults and larvæ of certain Coccinellids and to adults of Braconid species and larvæ of a Cecidomyid. In general the aphid hosts were more resistant than their parasites and predators to the D.D.T. and B.H.C. preparations used.

182. WAY, M. J., HOPKINS, Barbara and SMITH, Pauline M. 1949. *Photoperiodism and diapause in insects.* Nature, **164**, 615.

At a constant temperature of 24°C. it was found that day length during the larval period of *Diataraxia oleracea* (the tomato moth) influenced diapause in the resulting pupæ. Practically 100 per cent. of pupæ from larvæ reared at 0, 4 and 8 hours artificial light per 24 hours were of the diapause type. When larvæ were reared with 16 hours light per 24 or under continuous light, practically all the resulting pupæ were non diapause. Light has some influence on diapause of *Pieris brassicæ* (Large white butterfly) *Mammestra brassicæ* (Cabbage Moth) and *Phædon cochleariæ* (Mustard beetle).

Woburn Experimental Station

PUBLICATIONS FROM THE STATION IN 1948–9

183. (1) MANN, H. H. and BARNES, T. W. 1949. *The competition between barley and certain weeds under controlled conditions.* IV. *Competition with* Stellaria media. Ann. Appl. Biol. (In the press).

184. (2) MANN, H. H. and BARNES, T. W. 1949. *The behaviour of nitrogenous manures in the soil.* I. *The loss of manurial nitrogen.* J. Agric. Sci. (In the press).

185. (3) BARNES, T. W. 1949. *The formation of nitrates in soil following various crop rotations.* J. Agric. Sci. (In the press).

186. (4) MANN, H. H. 1949. *Soya beans in England.* The Countryman, December, 1949.

GENERAL PUBLICATIONS

187. GARNER, H. V. 1948. *The irrigation of sugar beet.* Brit. Sugar Beet Rev., **16**, 109.

188. GARNER, H. V. 1948. *Top dressing wheat.* Farming, **2**, 268.

189. GARNER, H. V. 1949. *Manuring of root crops.* I. *Sugar beet.* Farming, **3**, 36.

190. GARNER, H. V. 1949. *Manuring of root crops.* II. *Mangolds and turnips.* Farming, **3**, 76.

191. OGG, W. G. 1948. *Soil and the farmer.* J. Farmers' Club, **2**, 14.

192. OGG, W. G. 1948. *The role of fertilizers in the national economy.* Fertilizer Society, June 1948. Also published in Ann. Agron., **6**, 687.

193. OGG, W. G. 1949. *Improving soil productivity : temperate climates.* U.N. Conf. on the Conservation and Utilization of Resources. Introductory paper prepared for Section Meetings : Land Resources 5(a). Improving Soil productivity.

194. OGG, W. G. 1949. *Fertilizers in present-day agriculture.* "The Times" Supplement on British Agriculture, December 1949.

Publications of the Rothamsted Experimental Station

For Farmers

"Manuring for Higher Crop Production," by Sir E. J. Russell, D.Sc., F.R.S., 1917. The University Press, Cambridge, 5/6.

*"Artificial Fertilisers in Modern Agriculture," by Sir E. J. Russell, D.Sc., F.R.S. Bulletin No. 28, Ministry of Agriculture and Fisheries, Third Edition, revised 1939. H.M. Stationery Office, or from the Secretary, Rothamsted Experimental Station, Harpenden. Cloth, 4/6 post free: or paper cover, 3/5 post free.

"Weeds of Farmland," by Winifred E. Brenchley, D.Sc., F.L.S. 1920. Longmans, Green & Co., London. 12/6.

Rothamsted Conference Reports: being papers by practical farmers and scientific experts. Obtainable from the Secretary, Rothamsted Experimental Station, Harpenden.

"The Manuring of Potatoes." 1/6.
(1)*"The Growing of Lucerne." 1/6.
(2) "The Culture and Manuring of Fodder Crops." 1/6.
(3)*"Green Manuring; its Possibilities and Limitations in Practice." 2/–.
(4) "The Culture and Manuring of Sugar Beet." 2/6.
(5) "The Science of Cultivation." 2/–.
(6) "Power for Cultivation and Haulage on the Farm." 2/6.
(7) "Malting Barley." 2/6.
(8) "Recent Changes in Systems of Husbandry in England." 2/6.
(9) "The Hertfordshire Agricultural Situation; Can it be Improved?" 2/–.
(10) "The Growth of Cheaper Winter Food for Live Stock." 2/6.
(11) "The Making of New Grassland; Experiences of Practical Farmers." 2/6.
(12) "The Place and Management of Sheep in Modern Farming." 1/6.
(13) "The Technique of Field Experiments." 1/6.
(14) "Mechanisation and British Agriculture." 2/6.
(15) "Recent Developments in Market Gardening." 2/–.
(16)*"Problems of Potato Growing." 2/–.
(17) "Modern Changes in the Treatment of Light Soil." 2/–.
(18)*"Foul Brood Diseases of Bees." 1/6.
(19) "The Production of Pigs for Bacon." 1/6.
(20)*"The Cause and Control of Swarming Bees." 1/6.
(21) "The Use of Electricity in Agriculture." 2/–.
(22) "Diseases of Bees." 1/6.

* Out of print.

Numbers 1 to 20 inclusive are also published in book form with the exception of 1–5 (Vol. I) and 16–20 (Vol. IV), which are out of print. Vol. II (6–10) and Vol. III (11–15), 10/- each, postage extra.

For Students and Agricultural Experts

"The Rothamsted Memoirs on Agricultural Science." Quarto Series, vol. 4 (1914–1934), 20/–. Octavo Series, vols. 1–7 (1847–1898), 30/– each. (Out of stock.) Royal Octavo, vol. 8 (1900–1912), vol. 9 (1909–1916), vol. 10 (1916–1920), vol. 11 (1920–1922), 32/6 each, vol. 12 (1922–1925), vol. 13 (1925–1927), 33/6 each, vol. 14 (1928–1930), 35/–, vol. 15 (1922–1931), vol. 16 (1922–1932), vol. 17 (1931–1933), vol. 18 (1923–1934), vol. 19 (1933–1935), vol. 20 (1935–1936), vol. 21 (1936–1937), vol. 22 (1938–1939), vol. 23 (1939–1940), 36/- each, vol. 24 (1940–41), 60/-. Foreign postage extra. Obtainable from the Secretary, Rothamsted Experimental Station, Harpenden.

"The Rothamsted Monographs on Agricultural Science," edited by Sir E. J. Russell, D.Sc., F.R.S. Published by Longmans, Green & Co., 39 Paternoster Row, London, E.C.4.
*"Soil Conditions and Plant Growth," by E. J. Russell, D.Sc., F.R.S. Seventh Edition, 1937. 21/–.
"The Micro-Organisms of the Soil," by E. J. Russell and Staff of the Rothamsted Experimental Station, 1923. 7/6.
"Manuring of Grassland for Hay," by Winifred E. Brenchley, D.Sc., F.L.S. 1924. 12/6.
"A List of British Aphides" (including notes on their recorded distribution and food-plants in Britain and a food-plant index), by J. Davidson, D.Sc., F.L.S. 1925. 12/6.
*"The Physical Properties of the Soil," by B. A. Keen, D.Sc., F.R.S. 1931. 21/–.
"Problems in Soil Microbiology," by D. Ward Cutler, M.A., and Lettice M. Crump, M.Sc. 1935. 9/–.
"Fifty Years of Field Experiments at the Woburn Experimental Station," by E. J. Russell, D.Sc., F.R.S., and J. A. Voelcker, C.I.E., M.A., Ph.D., with a Statistical Report by W. G. Cochran, M.A. (Rothamsted Statistics Department). 1936. 21/–.

"The Feeding of Crops and Stock," by A. D. Hall, K.C.B., F.R.S., Parts I and II revised by W. G. Ogg, M.A., Ph.D. Third Edition, 1944. John Murray, London. 12/–.

"The Suppression of Weeds by Fertilizers and Chemicals." by H. C. Long and Winifred E. Brenchley. Third and enlarged Edition, 1949. Crosby Lockwood & Co., London.

"Plant Nutrition and Crop Production" (being the Hitchcock Lectures, 1924, University of California), by E. J. Russell, D.Sc., F.R.S. The University of California Press and the University Press, Cambridge. 12/6.

"Report on the Work of the Imperial Council of Agricultural Research in Applying Science to Crop Production in India," by Sir John Russell, D.Sc., F.R.S. Reprinted

Edition, 1939. Government of India Press, Simla. 3/3. Obtainable from the High Commissioner for India, India House, Aldwych, London, W.C.2.

"Inorganic Plant Poisons and Stimulants," by Winifred E. Brenchley, D.Sc., F.L.S. Second Edition, revised and enlarged. 1927. The University Press, Cambridge. 10/6.

"Root Disease Fungi," by S. D. Garrett, M.A. 1944. Chronica Botanica Co., Waltham, Mass. $4.50.

"Plant Viruses and Virus Diseases," by F. C. Bawden, M.A. Third Edition, 1950. Chronica Botanica Co., Waltham, Mass. $4.75.

"Gall Midges of Economic Importance," Vols. I-IV, VI, by H. F. Barnes. 1946, 1948 and 1949, Crosby Lockwood, London. 12/6, 15/–, 15/–, 15/–, 15/–.

"Plant Diseases," by F. C. Bawden. Nelson, Edinburgh. 1948. 7/6.

"Laboratory Methods for Work with Plant and Soil Nematodes," by T. Goodey, D.Sc., F.R.S. 1949. Ministry of Agriculture Technical Bulletin No. 2.

"The Importance of Bees in Orchards," by C. G. Butler, Ph.D. 1948. Ministry of Agriculture Bulletin No. 328.

"Beehives," by C. G. Butler, Ph.D. Ministry of Agriculture Bulletin No. 144. 1949. 9d.

"The Honeybee. An Introduction to her Sense, Physiology and Behaviour," by C. G. Butler. 1949. Oxford University Press, London. 10/6.

The following are obtainable from the Secretary, Rothamsted Experimental Station, Harpenden.

"Agricultural Investigations at Rothamsted, England during a Period of 50 Years," by Sir Joseph Henry Gilbert, M.A., LL.D., F.R.S., etc. 1895. 3/6.

"Guide to the Experimental Plots, Rothamsted Experimental Station, Harpenden." 1913. John Murray, London. 1/–.

"A Descriptive Catalogue of Printed Books on Agriculture from 1471 to 1840, contained in the Rothamsted Library." Second Edition, 1940. Cloth cover, 15/–; paper cover, 12/–. Packing and postage extra :— British Isles, 9d. ; Overseas, Dominions and other countries, 1/3.

Supplement to the above: List of additions since 1940. 2/6.

The Rothamsted Experimental Station Reports

1908 to 1914 (annual)	1/– each
1915–1917, 1918–1920 (triennial) 1921–1922, 1923–24, 1925–1926, 1927–1928 (biennial) 1929 to 1937 (annual) (1933 out of stock)	2/6 each
1938	5/–
1939–1945 (war years)	5/–
1946, 1947	3/– each
1948, 1949	5/– each

Foreign postage extra.

For Use in Farm Institutes

"A Student's Book on Soils and Manures," by E. J. Russell, D.Sc., F.R.S. Fourth Edition, 1948. The University Press, Cambridge. 8/6.

For Use in Schools

"Lessons on Soil," by E. J. Russell, D.Sc., F.R.S. 1926. The University Press, Cambridge. 3/–.

For General Readers

"The Farm and the Nation," by E. J. Russell, D.Sc., F.R.S. 1933. George Allen and Unwin, London. 7/6.

"The Fertility of the Soil," by E. J. Russell, D.Sc., F.R.S., 1913. The University Press, Cambridge. 4/–.

"The Possibilities of British Agriculture," by Sir Henry Rew, K.C.B., and Sir E. J. Russell, D.Sc., F.R.S. 1938. 1/–. Obtainable from the Secretary, Rothamsted Experimental Station, Harpenden.

"Personal Reminiscences of Rothamsted Experimental Station," 1872–1922, by E. Grey, formerly Superintendent of the Experimental Fields. 5/–. (Out of stock.)

"Cottage Life in a Hertfordshire Village," by E. Grey. 1935. A companion volume to "Personal Reminiscences of Rothamsted Experimental Station." Fisher, Knight & Co., St. Albans. 3/6. (Out of stock.)

"English Farming," by E. J. Russell. 1941. William Collins Sons & Co., London. 4/6.

Other Books by Members of the Staff

"Evolution, Heredity and Variation," by D. W. Cutler, M.A., F.L.S. 1932. Christophers, London. 4/6.

"Statistical Methods for Research Workers," by R. A. Fisher, Sc.D., F.R.S. Ninth Edition, 1944. Oliver & Boyd, Edinburgh. 16/–.

"Statistical Tables for Biological, Medical and Agricultural Research," by R. A. Fisher, M.A., Sc.D., F.R.S., and F. Yates, Sc.D., F.R.S. Third Edition, 1948. Oliver & Boyd, Edinburgh. 16/–.

"Sampling Methods for Censuses and Surveys," by F. Yates, Sc.D., F.R.S. Griffin & Co., London. 24/–.

"Plant Growth Substances," by Hugh Nicol, Ph.D., F.R.I.C. Second Edition, 1940. Leonard Hill, London. 3/6.

"Microbes by the Million," by Hugh Nicol, Ph.D. 1939. Penguin Books, Harmondsworth. 9d.

"Biological Control of Insects," by Hugh Nicol, Ph.D. 1943. Penguin Books. 9d.

"Proteins and Life," by M. V. Tracey. 1948. Pilot Press, London. 10/6.

Mezzotint Engravings

Mezzotint Engravings of Portraits of the Founders of the Station, Sir J. B. Lawes (H. Herkomer) and Sir J. H. Gilbert (F. O. Salisbury), by Julia Clutterbuck, A.R.E.

Signed Engraver's Proofs on India Paper, £4 4s. each

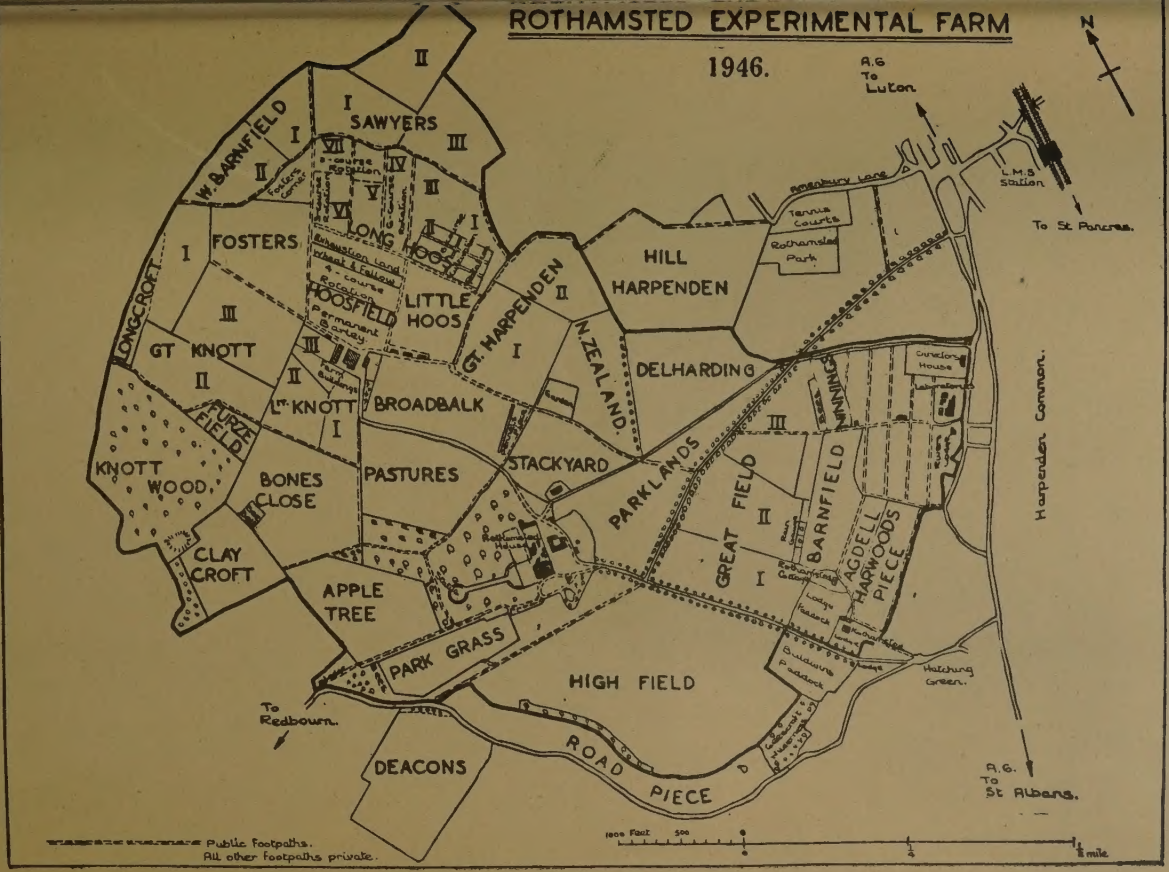
Ordinary Lettered Proofs on hand-made paper, £2 2s. each.

To be obtained from the Secretary, Rothamsted Experimental Station, Harpenden.

Plans and Drawings of the Old Rothamsted Laboratory, 1852

These drawings show the old Rothamsted Laboratory erected in 1851, the first important laboratory devoted to agricultural science, and the one in which much of the classical work of Lawes and Gilbert was done: it survived till 1914.

The size of the volume is 21½ in. by 14½ in.: it consists of four full-page lithographs made from drawings by Charles Lawes, son of Sir J. B. Lawes. £1 per copy (post free).


ROTHAMSTED EXPERIMENTAL FARM
1946.
N
A.6 To Luton
L.M.S Station
To St Pancras.
Broadbury Lane
Tennis Courts
Rothamsted Park
HILL HARPENDEN
N.ZEALAND.
DELHARDING
Cunclers House
Harpenden Common.
W. BARNFIELD
SAWYERS
FOSTERS
LONG HOOS
HOOSFIELD
LITTLE HOOS
GT. HARPENDEN
LONGCROFT
GT KNOTT
Lt. KNOTT
BROADBALK
FURZEFIELD
KNOTT WOOD.
BONES CLOSE
PASTURES
STACKYARD
PARKLANDS
GREAT FIELD
BARNFIELD
AGDELL
HARWOODS
PIECE
CLAY CROFT
APPLE TREE
PARK GRASS
HIGH FIELD
Hatching Green.
To Redbourn.
DEACONS
ROAD PIECE
A.6. To St Albans.
Public Footpaths.
All other footpaths private.
1000 Feet 500
¼
½ mile